VOLUME 66 • OCTOBER 1957 • NUMBER 4

A.M.A. ARCHIVES OF OTOLARYNGOLOGY

ama in Action
George M. Coates

Voice Therapy
F. Bertram Briess

Mobilization of the Stapes in Otosclerosis by a Transtympanic Technique
Lucian W. Alexander

The Problem of Permeability and Anesthesia of the Tympanic Membrane
George I. Uhde

Intravascular Agglutination of the Blood
Edmund Prince Fowler

The Evolutionary History of Man from the Evidence of the Nose and Larynx
Sir Victor Negus

The Function of the Paranasal Sinuses
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A Knife for Cutting the Stapedius Tendon
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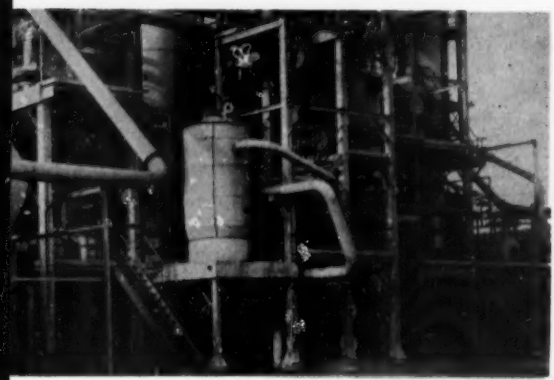

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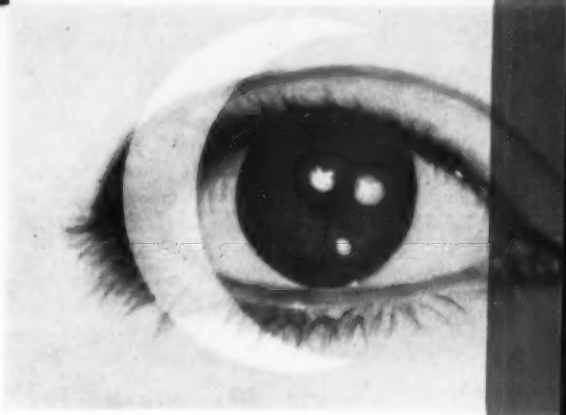

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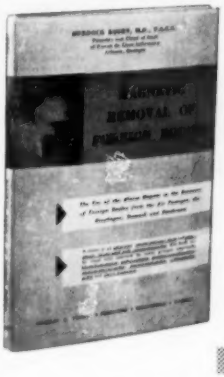

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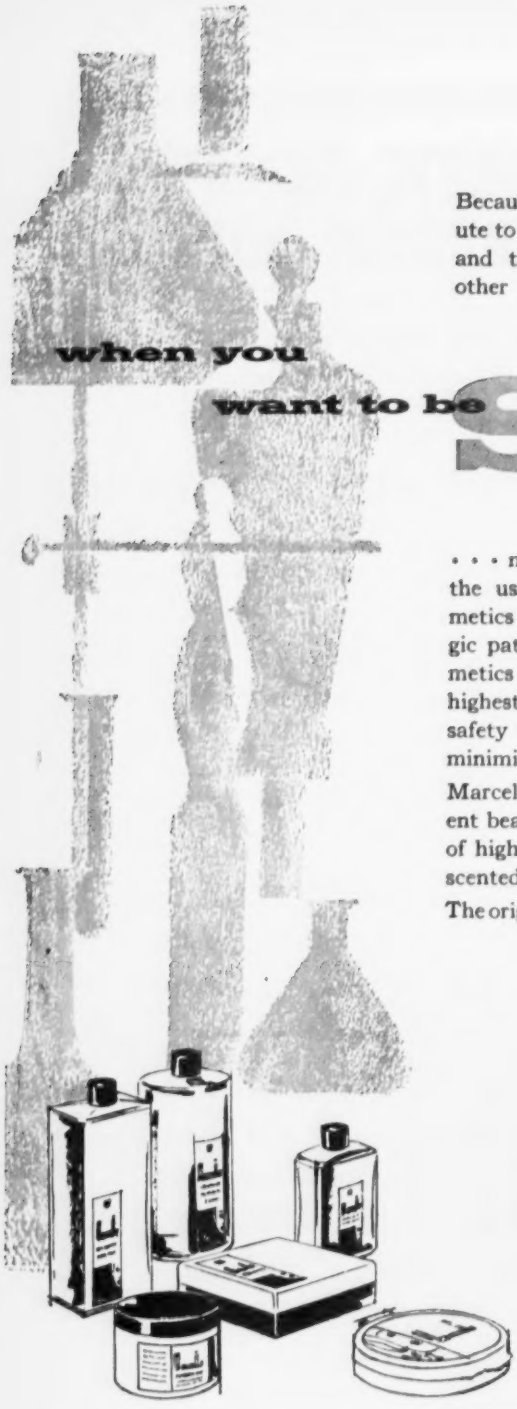

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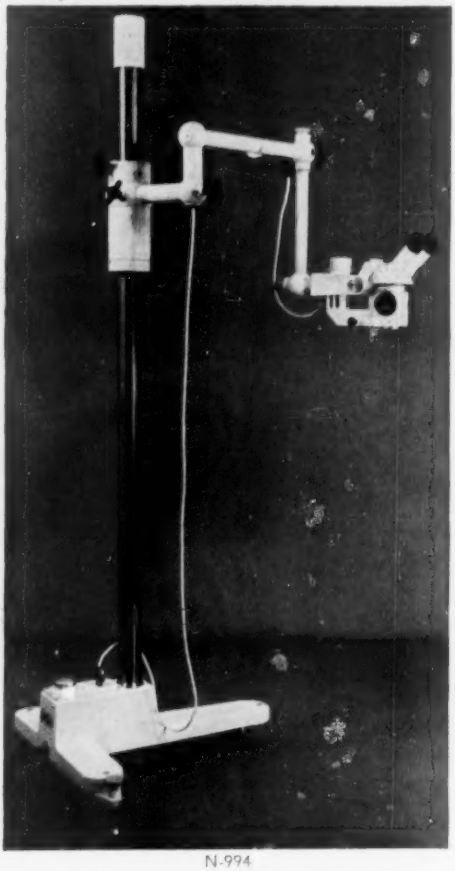

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Editorials

ama in action!

Persons who have been quick to criticize the American Medical Association in years past would find it difficult to argue with the impressive story of progress and public service told in the Association's newest publication, "ama in action!"

The well-illustrated 44-page booklet, just released to state and county medical societies and key opinion leaders around the nation, draws a factual picture of today's A. M. A.—a dynamic, public-spirited organization moving ahead toward better medicine, better patient care, and better public health.

Because the A. M. A. is basically a scientific organization, the booklet leads off with the story of the activities of its scientific councils and committees, which are geared primarily for practicing physicians but ultimately benefit the patient.

Early in the booklet it is pointed out that "modern medicine moves ahead at a fantastic pace." "Keeping on top of this expanding knowledge is a staggering job for a physician. . . . AMA makes its greatest contribution to better medicine by providing information which helps physicians answer these questions—by gathering data, correlating it, evaluating it and summarizing it—and by channeling it speedily to members." Cited are the informational services of scientific councils and committees and the work of the Council on Drugs, Council on Foods and Nutrition, and others to maintain high standards in medicine and therapeutics. Important aids in bringing better medicine to the American public via the practicing physician include the Association's many scientific publications, such as the weekly *Journal of the American Medical Association* and the nine monthly specialty journals, the two huge postgraduate meetings each year, and such devices as exhibits, films, and library services.

Better care for patients is brought about, the booklet states, by Association efforts to insure a growing supply of well-trained physicians as well as allied medical personnel, to improve hospital standards, to foster better medical services in industry and the Armed Forces, and to reduce the menace of medical quackery.

What the A. M. A. is doing to bring medical care to more people is one of the most positive stories told in the booklet. Through its own placement service and by efforts to stimulate communities into action, the Association is getting physicians into areas needing physicians. It is also working with other groups to improve or expand existing physical facilities or to build new facilities where necessary. Also described are A. M. A. efforts to put medical services at the economic reach of more Americans, such as by promotion and development of all types of voluntary health insurance and assumption of leadership by the medical profession in supervision of indigent medical care programs at the local level.

Health educational activities of the medical profession, utilizing every medium—literature, the spoken word, radio and television, films, and exhibits—all contribute to a public better-informed on medicine and health. Health education, of course, paves the way for better public health.

"The medical profession, with its finger on the nation's pulse, is a dynamic force working for better health," the booklet points out. "Physicians today are

spending many extra hours translating their knowledge into concrete means of creating better health and life for everyone. They are providing leadership and guidance in a multitude of efforts to achieve these goals." A. M. A. efforts to develop and maintain safeguards and standards for medical education, hospitals, drugs, and chemical products in home and industry, as well as for medical care programs operated by industry, government, or the Armed Forces, fall into this category. So also do Association research efforts in the fields of mental health, geriatrics, nutrition, auto safety, and medical economics, to name but a few.

By pushing for sound health proposals and openly fighting those that are not sound, the medical profession makes another vital contribution to public health. The story which "ama in action!" tells is one in which every physician can be proud. For, as the booklet points out in its concluding paragraphs, "AMA's physician-members are stockholders in a unique humanitarian enterprise whose profits—services and medical progress—are shared by the public. Who can put a pricetag on health or measure the monetary value of physicians' constant efforts for better medicine and better health? It is because life itself is priceless that AMA will always continue its work."

GEORGE M. COATES, M.D.

A.M.A. ARCHIVES OF
OTOLARYNGOLOGY

Voice Therapy

Part I. Identification of Specific Laryngeal Muscle Dysfunction by Voice Testing

F. BERTRAM BRIESS, Syracuse, N. Y.

Historical

It is not known when voice therapy actually started. However, corrective voice training has been practiced in Europe as far back as 1850, although treatments were very empirical at first. Manuel Garcia's invention of the laryngoscope in 1854 set off a period of profound research. German and French scientists—physicians, physiologists, physicists, and voice teachers—spared no efforts in their study of the vocal organs and their functions.

In 1905, Gutzmann,[1,2] lecturing at the University of Berlin, repeated and further explained Johannes Müller's experiment demonstrating that falsetto function of the voice was seen to involve "free-edge" vibration of the vocal cords and that this could be visualized in the postmortem larynx; further, that "full" vibration of the cord corresponded to the "fundamental" tone of the voice teachers and was due primarily to thyroarytenoid muscle function.

The postmortem larynx was mounted as shown in Figure 1.

1. The anterior scale pan was weighted to tip the larynx anteriorly and thereby lengthen the cords, demonstrating the isolated cricothyroid muscle.

2. The lateral scale pans were weighted, producing pressure on the inside of the larynx through the attached metal plates. Gutzmann explained that this lateral pressure largely eliminated the cricothyroid contraction and produced full vibration or fundamental tone in phonation.

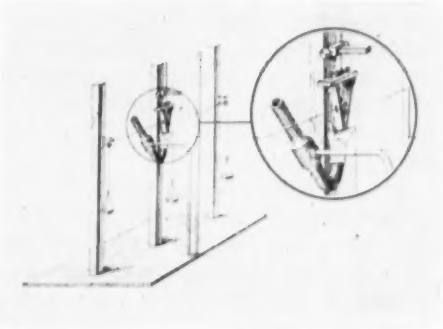

Fig. 1.—Instrument used by Gutzmann (following J. Müller).

3. Applying breath to the glass mouthpiece forced air through the larynx, setting the cords in vibration. The amount of air pressure was measured by the connected mercury manometer.

This experiment was repeated many times in demonstration in classes. It is of interest to note that the students attending included officially delegated administrators and teachers of elementary, secondary, and high schools, as well as University Faculty. A lively interest in the mechanics of the voice and healthy voice production in students was held to be part of the responsibility of public education.

Undoubtedly the greatest single contribution by any one individual during the early decades of the 20th century was made by

Accepted for publication March 4, 1957.

Instructor, Department of Otolaryngology, State University of New York Upstate Medical Center at Syracuse.

Otto Iro of Vienna. In his work with patients and in his book Diagnosis of the Voice[3] he placed major emphasis on "register divergence" as the source of the majority of voice difficulties. He used the phrase "register divergence" to indicate a clashing of function between the "fundamental" and the "falsetto function" of Gutzmann.

More recently, research has been concentrated on investigating larynx and pharynx positions, cartilaginous movement, and analysis and measurement of sound waves, as well as motion picture photography of the vocal cords. Study of the finished product, namely, sound, has revealed much regarding speech or articulation abnormalities. However, no equipment is yet available which will visually demonstrate for study the essential changes in sound so easily detected by the human ear.

The major practical application of better understanding of voice function ultimately has always been to restore the abnormal voice to normal function. Yet a basic understanding of the physiology of voice production is still being sought. Empirical methods were difficult to assess for two main reasons. First, the names of various anatomical structures, and particularly their functions, were not fully known by either physicians or voice teachers. Secondly, professional jealousy held back many in both fields from pooling both their talents and collected impressions of exactly how voice, in its many variations, was produced by the human being.

It is difficult for the physician to relate muscle function during phonation to the previously studied textbook descriptions of function during respiration and to laboratory experiments of isolated muscle function when electrical stimuli are applied. However, on the basis of clinical experience with phonation, we now know that during voice production these muscles behave quite differently. For example, the function of the interarytenoid muscles is believed by some to be of great importance in phonation by those who consider the interarytenoids as

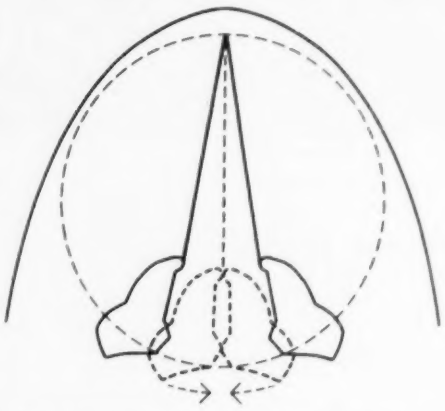

Fig. 2.—Vocal cords during phonation (in dynamic equilibrium).

adductors. However, we have learned that in phonation the posterior cricoarytenoids, together with their antagonists, the lateral cricoarytenoids, accomplish approximation of the arytenoids; yet this holds true only when cricothyroids and thyroarytenoids are in dynamic equilibrium (Fig. 2).

Figure 3 shows glottal aperture during healthy inspiration with the posterior cricoarytenoids contracting without any counterpull of the lateral cricoarytenoid muscles. In Figure 4, in whispering the lateral cricoarytenoids contract, while their antagonists are markedly relaxed.

Until now, no detailed reports have been given concerning the intimate relationship

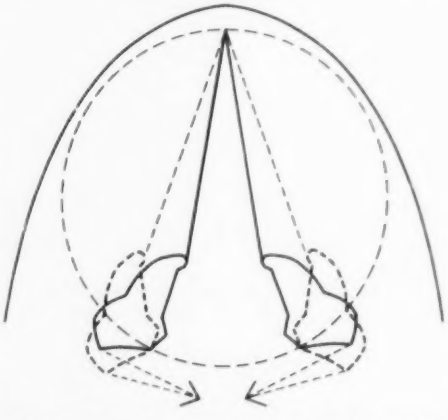

Fig. 3.—Glottal aperature during healthy inspiration.

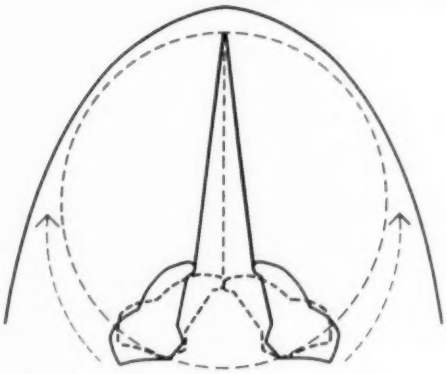

Fig. 4.—Glottal aperature during whispering—note posterior chink.

of the generator or larynx and its muscles which cause the vocal cords to move. This study has shed further light on the physiology of the larynx.

It is now held that it is primarily the balanced interplay of thyroarytenoid and cricothyroid, as well as posterior and lateral cricoarytenoid muscles that is essential for normal, healthy phonation. Slackening of one pair will cause hyperfunction of the antagonistic muscles and will disturb the dynamic equilibrium. This equilibrium is called dynamic because the balance of the muscles involved changes as pitch, volume, and quality change.

Translating the vocal terminology of Müller, Gutzmann, and Iro into the nomenclature of physiology, it is in large degree the imbalance (clash) of thyroarytenoid (fundamental) and cricothyroid (falsetto) function of the muscle pairs which is responsible for the majority of vocal problems because of their lack of dynamic equilibrium (register divergence).

Recently a new emphasis has been observed. Laryngologists have seen on a number of occasions benign lesions of the vocal cords cleared without resort to medication or surgery. Correction of poor breathing habits, chewing of words to purposefully focus attention on the muscles of chewing and thereby relieve tensions in the throat, as well as purposeful relaxation of the suprahyoid muscles for the same purpose, have produced disappearance of certain growths on the vocal cords. Improved voice has been noted in each of the cases which responded to treatment.[4,5]

Attention to the emotional tensions has been stressed by Moses,[6] and a psychosomatic approach has produced improved voice in many recorded instances.

Since a period of study under Iro, and many other professional voice teachers and laryngologists, I have been able to establish clinically a direct functional relationship between the musculature of the larynx during phonation and the anatomical terms so familiar to laryngologists. Tests for muscle function have been devised, and methods for treatment of voice disorders, including many which produce visible lesions on the vocal cords, have been developed on this basis. Classification of more than 5000 voices and treatment of more than 425 patients form the clinical background for this work. As early as 1920, it was found to be effective in not only causing the disappearance of singer's nodes but in reestablishing normal voice production for the patient. Subsequently, certain variations in the sequence of treatment phases have been found essential in dealing successfully with polyps, contact ulcers, papillomata, leukoplakia, etc.

Voice Testing

This procedure consists of the following steps. The specific order in which the steps occur must depend on the following: the condition of the patient; whether there is an obvious lesion on the cords; the pathological type of lesion; postoperative condition, if the laryngologist felt it necessary to resort to surgery; and psychosomatic assessment from combined information from laryngologist's and voice therapist's interviews.

1. Dehabiting
2. Classification of voice type
3. Classification of voice character
4. Divergence test
5. Cricoarytenoid test
6. Thyroarytenoid endurance test
7. Cricothyroid test

In the absence of any reported visible lesion by the otolaryngologist, voice testing may proceed without delay. However, with a visible lesion, or in fresh postoperative cases, rearrangement of testing procedure and often postponement of certain tests will be necessary. In these instances, therapy for specifically indicated muscle functions will precede.

During the various testing phases the patient has certain sensations; he feels tension or aches at varying locations of the larynx. He will complain about pain in the region of the arytenoids, or dryness "in the back of the throat," which will indicate hyperfunction of posterior cricoarytenoid muscles, or pain along the side(s) of the larynx up to the ear(s) if hyperfunction of the lateral cricoarytenoid muscles exists. The identical sensation may be caused by a hyperfunctioning cricothyroid, while hypofunction of thyroarytenoids cause a "lump" feeling below the cricoid.

Testing time depends on voice character, and physical and emotional condition of the patient, and may vary from 2 to 30 minutes or longer.

I. *Dehabiting.*—The following acquired habits during voice production may interfere with accurate testing and must be evaluated and sufficiently eliminated to allow testing to proceed.

A. Abusive breathing habits

1. Inspiration through partially closed cords (unhealthy inspiration)
2. Excessive intake of air—too much air too often.
3. Glottal attacks—excessive, forceful posterior closure of the cords heard at the beginning of syllables
4. Breathy voice stemming from bowed vocal cords. This can be quickly repaired within seconds and represents hyperfunction of the posterior cricoarytenoid, or on occasion interarytenoid muscles, as seen in untrained or partially trained voices, or on coughing or throat clearing
5. Excessive air escape caused by edema or lesions on the cords. The patient develops a habit by continually trying to compensate more and more for the waste of air due to the edema or lesion

B. Pitch adjustments—too low pitch with too little or too much volume as in pseudoauthority or in psychosomatic overlay cases

C. Sound distortion representing abusive exaggerated muscle response to mirth, sadness, etc.

D. Whisper-like phonation in patients working in hospitals, libraries, and places where normal volume of voice is shunned.

Each of these habits cannot be dealt with singly and corrected completely before therapy of specific muscles results in voice improvement. In fact, voice may temporarily become less clear and weaker while the above habits are being corrected.

II. *Classification of Voices.*—A complete test of the altered dynamic equilibrium will enable the voice diagnostician to point out specifically the muscle pair which cause the disturbance in the compensating interplay of functions and to ascertain both voice character and voice type.

It is generally understood that there is no functioning difference between singing and speaking; any speaking voice must fall into one of the categories to be described.

The untrained voice may show a very limited compass range compared with a trained voice belonging to the same type; however, during the divergence test a divergence will occur in both voices at the same pitch.

III. *Character.*—In voice therapy, the mixture of thyroarytenoid muscle function and cricothyroid muscle function in a voice during correct phonation while volume is kept full over the entire voice range or compass changes according to pitch. The lowest tone of the natural voice compass may consist of 90% thyroarytenoid and 10% cricothyroid function, while the highest tone may be compounded of 10% thyroarytenoid plus 90% cricothyroid function. Somewhere between the lowest and highest points of the voice range will be a pitch with a 50:50 tone structure. This proportion of mixture determines voice character.

A "robust" voice is characterized by a predominating thyroarytenoid contraction or full vibration function of the cords, and will therefore endure more punishment than a "delicate" character voice with its "weaker"

thyroarytenoid but "stronger" cricothyroid and posterior cricoarytenoid muscles.

IV. *Type.*—No two voices are absolutely identical; yet voices of great similarity can be found which can be classified as belonging to the same type. Range and timbre are important qualities in determining the voice type. There are 10 major types which divide voices into high, medium, and low ones, with several in-between or subtypes. The voice expert classifies these subtypes as soprano, mezzo-soprano, mezzo-alto, alto, contralto, tenor, baritone, bass-baritone, and bass voices.

Voice teachers and theatrical managers also discriminate between dramatic and lyric voices, and divide female voices belonging to the high type into high-dramatic, dramatic, lyric-dramatic, lyric, coloratura, and soubrette voices, and male voices into heroic, dramatic (or robust), lyric, and buffo tenors. Similar distinctions exist for the other major voice types.

Unfortunately these classifications are being based mostly on individual physical appearance and artistic abilities, sometimes on method of voice production, and very frequently these classifications are erroneous, as they are made without regard to natural functioning condition.

Misclassification of this sort will always result in organic voice problems. Similarly, persons who lower or raise their natural speaking voice for various reasons (as in pseudoauthority cases, or because the patient dislikes his high- or low-pitched voice) will sooner or later upset the dynamic equilibrium of the vocal muscles, and develop voice difficulties. Phonation under such distorted functioning condition may result in lesions which the doctor can observe.

These voice types are by no means just musical distinctions; they are of great importance in voice therapy for diagnostic purposes, especially in conducting the divergence test.

Divergence Test.—This test is a combined examination of thyroarytenoid and cricothyroid muscle functions. It determines both voice type and voice character. The patient is asked to produce a phrase rich in "O" vowels such as "Oh!" "No!" By varying the pitch from low to high and varying the emphasis on the "Oh!" and the "No!" while maintaining constant volume a divergence of function or audible gap in sound production will be heard. Upon repetition of this procedure the gap will occur again and again at the same pitch.

The exact musical pitch at the point where the gap or divergence occurs indicates the voice type. For example, in the low male voice with no lesion present this function divergence occurs at B flat to C sharp. In the low female voice, such as alto and contralto, two divergences occur—one on ascending the full range or compass of the voice and a second much lower-pitched divergence on descending. For example, it occurs between D flat and E sharp on ascending and from E to F sharp an octave lower on descending. There is a specific occurrence pitch for each type and subtype.

The voice is further classified by this test as to character, whether robust or delicate, since again in robust voices thyroarytenoid function predominates and in delicate voices cricothyroid function predominates.

It is in this way that the voice diagnostician purposely disturbs the dynamic equilibrium of the vocal mechanism to be examined. He irritates momentarily the interchange between thyroarytenoids and cricothyroids to provoke a clashing of functions. This clashing or acute divergence is the audible gap in sound production heard during the testing.

In cases of polyps, papillomas, and leukoplakia, or after surgery, it will not be possible to classify a voice at once. The function test ought not to be made in such cases, before therapy has eliminated the causes of abuse which were responsible for producing such lesions. Even then, the divergence test will be a limited one, as it can be conducted only within a certain limited range as a divergence test without regard to pitch. This range will be widened, depending on the degree of improvement through therapeutic treatment.

This test is applied over the entire voice compass in cases of nodes, contact ulcers, edemas, and all functional disturbances. There will never be a smooth transition from "full vibration" (fundamental or natural) function to "free edge vibration" (falsetto), if swellings or nodules, unilateral or bilateral, exist. This function divergence will show as long as the lesions remain unchanged; the disinclination of these functions to "mix" will lessen when the lesions diminish. However, the voice expert knows that such a divergence will not completely disappear, even if the doctor's examination proves that the cords are "free of a lesion." A diathesis remains until the voice instrument is sufficiently reeducated. Slackened muscles must be reactivated, and hyperfunctioning muscles must be relaxed in order to establish a dynamic equilibrium—the only way to avoid recurrence of the lesion.

There are various degrees of function divergences. An acute divergence might be just a temporary indication of bad voice production and may disappear after a few seconds. It may not even show during a different testing phase.

A chronic divergence, however, usually indicates the presence of a lesion which the doctor can observe. The diagnostician will always refer such a patient back to the laryngologist for a detailed diagnosis on kind of tissue change, as well as size and exact location of lesion.

There are partial and total divergences; some are reparable; others are beyond repair.

Irreparable divergences are found in abuse cases of long standing, or in senile patients when reactivation of the defective muscle fails to materialize. It is remarkable that very often no abnormality can be seen in the patient's throat in spite of the existence of total divergence, and it is believed that neither calcification nor ossification can be made responsible for such a divergence. In cases of irreparable function divergence the therapist will restrict the patient's voice compass to a limited range; at the same time he will train the predominating muscle to endure more without permitting hyperfunction to develop.

Frequently function divergence is present in psychosomatic patients, and some diagnosticians feel that such a divergence has psychosomatic causes. Partial or even total elimination of emotional factors does not necessarily return the larynx to its natural function.

Test of Cricoarytenoid Muscles.—Testing of lateral and posterior cricoarytenoid muscles is usually one single procedure.

A. The patient is asked to sustain a round "O" vowel (as in "Go"), and then to diminish it into a very breathy sound. If the patient fails to accomplish this task after several attempts, it may be assumed that a hyperfunction of the posterior cricoarytenoids exists.

B. In order to determine original hyper- or hypofunction of either muscles, these tests are continued with pitch being gradually raised, while the "O" vowel is sustained. If the patient manages to relax phonation into a breathier sound while ascending, the diagnostician knows that the hyperfunction of the posterior cricoarytenoid muscles is based on a hypofunctioning lateral cricoarytenoid muscle, most frequently caused by a hypofunctioning condition of the cricothyroid muscles. Hypofunction of posterior cricoarytenoids makes it impossible for the patient to sustain round "O" vowels without fading into breathiness.

Endurance Test of Thyroarytenoid Muscles.—The thyroarytenoid muscles are responsible for the "full vibration" function. The vocal cords are shortened and thickened when the thyroarytenoids contract, and the antagonistic cricothyroids relax at the same time. The full mass of the cords vibrate when air from the trachea is blown upon them.

In a so-called "hyperfunctioning voice" the thyroarytenoids are always the last muscles to be affected because they can endure most; therefore the endurance test will tell the stage of abuse. This test is used before and during therapeutic treatments, except in cases of polyps, papillomas, or

leukoplakia. The endurance test will have to be conducted with great caution if a chronic or total function divergence exists, and in instances of complete absence of "free edge vibration."

Untrained or incorrectly trained voices will be tested within the lower and middle range of their compass, while trained voices are tested over the entire compass. The tests are conducted with sustained tones at moderate to full volume.

Cricothyroid Test.—The divergence test has already identified hypofunction or even collapse of cricothyroid action. The cricothyroid test detects hyperfunction of this muscle pair.

Frequently, in untrained voices there is a complete lack of "free edge vibration" (collapse of cricothyroid) or in trained voices a stiffening of the falsetto function or hyperfunction of cricothyroid.

The diagnostician is unable to judge by hearing only; however, he knows that there are certain indications which he can see in the patient's face and neck during the testing procedure.

The patient is requested to sustain a round "O" vowel of reasonably good volume, and then to decrease the sound while ascending slowly over one or one and a half octaves—into a fine, gentle "free edge vibration" tone. The patient will attempt this task under great strain; efforts will show in muscle contraction outside the larynx as well as in his face, if a hyperfunction of cricothyroid exists. The patient will raise his head or at least his eyebrows. He will frown and in some cases may move his ears.

The test is completed by asking the patient to sustain a very gentle "free edge vibration" tone on "O" or "U" at the high pitch, and to increase the tone while descending over one octave into a substantial "full vibration" tone, which will be impossible for the patient with cricothyroid hyperfunction.

Hypofunction of cricothyroids can only be determined during the divergence test.

Prognosis.—After testing procedures have established abuse type and classification, the therapist should be able to furnish the laryngologist a fairly reliable prognosis as to type of lesion the untreated patient will produce if abuse persists and progresses.

It is found that the same type of abuse may produce different lesions in voices of different types and characters. The kind of abuse which would form a polyp or papilloma in patients with "robust" voices may result in leukoplakia in patients whose voices belong to a "delicate" character.

Voices belonging to a particular type and character are apt to form certain lesions when abused, while voices of other types and characters decline to do so. For instance, nodes are very rare in men with voices of the low type and robust characters, as well as in high voices of the "delicate" characters. However, they develop most often in low and medium type voices of the "delicate" categories in women.

Polyps are seen most frequently in men with low, medium, and high type voices of the "robust" character groups, and in women whose voices belong to the low type and "robust" characters.

Summary

The testing methods herein described stress the importance of the larynx with its vocal cords and intrinsic and cricothyroid muscles as the generator of sound used in voice production. Repeated use of the divergence, cricoarytenoid, endurance, and cricothyroid tests enables me to classify voices very exactingly as to type and character. They further indicate which muscle pairs are functioning out of balance. This information has been used in the testing and treatment of 425 patients with voice difficulties and benign lesions involving the vocal cords. The material presented forms the basis on which voice therapy in this department of otolaryngology is constructed. Subsequent papers will deal with the specific therapy of lesions, such as contact ulcers, singer's nodes, laryngeal polyps, etc.

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Mobilization of the Stapes in Otosclerosis by a Transtympanic Technique

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Mobilization of the stapes as a method of management of otosclerotic deafness has had a checkered history.[1,2] It is just 80 years ago that Kessel failed with it, after he had previously failed to correct stapedial ankylosis caused by suppuration by removal of the drum, malleus, and incus, and as he was to fail later with total stapedectomy. Boucheron, in 1888, reported mobilization of the stapes in 60 cases, and two years later Miot reported 200 cases. Both had some good results, but in America, between 1891 and 1893, Blake, Jack, and Burnett all had such unsatisfactory results that they soon abandoned this operation in favor of total removal of the stapes.

In 1900, Siebenmann flatly stated that all operations on the stapes, whether mobilization or excision, were useless. The previous year, Faraci, although he had had only limited success with mobilization, predicted that when the technique was eventually perfected, a great stride in scientific progress would have been made. Time seems to have proved him right and Siebenmann wrong, though more than 50 years were to elapse before the operation was revived by Rosen, as the result of a curious and dramatic mischance.[1,2] He had devised a procedure, consisting of instrumental palpation of the stapes after elevation of the lower half of the tympanic membrane, to demonstrate the suitability of the fenestration operation in otosclerosis. One patient whom he was testing had a sudden restoration of acute hearing in the course of the operation, apparently because the stapes had been accidentally mobilized. Since that time Rosen has employed and advocated mobilization of the stapes as a definitive operation, and many others have followed his lead.

It is not clear why the mobilization operation was abandoned at the turn of the century or why it was forgotten for so long a time. Its failures and risks when it was first employed are, however, easy to explain. They were not due to errors in principle but rather to the unpropitious circumstances in which the operation was originally performed. For one thing, the exposure provided by the myringotomy through which mobilization was attempted was insufficient for precise manipulation. For another, while all operations of this kind are now done under magnification, the excellent headlights and operating microscopes presently available were unknown in the last century. Finally, although specific statements are not made on this point in the early reports, it seems highly likely that infection must have occurred in many cases, for the protective antibiotics now in use are all of recent development.

Mobilization of the stapes is still a controversial operation, and, as often happens, a great deal of the discussion is not as dispassionate as it might be.[2] Much more light would be thrown upon the subject if it were constantly borne in mind that this operation is not a substitute for fenestration. On the contrary, in many cases in which mobilization of the stapes is performed definitively, fenestration would not be indicated at all, while in other cases it may be employed as a preliminary or tenta-

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tive procedure, one of its great advantages being that it can be followed by fenestration if it proves unsuccessful.

Rationale and Indications

Surgical mobilization of the ankylosed stapes has sound rationale behind it. This will be evident if the physiology of hearing is recollected. The auditory function, to state it as simply as possible, involves a continuous chain of physiologic processes. Impairment of hearing occurs when sound impulses are interrupted anywhere along this chain of transmission. If the stapes is fixed in the oval window, as it is in otosclerosis, stapedial vibrations are impossible and the auditory function is halted at this point.

Mobilization of the footplate, as Rosen and Bergman [2] express it, is "the utilization of nature's own pathway of sound conduction via the intact and freely moving ossicular chain." The structure of the ear is not changed, as it is in the fenestration operation, in which a new pathway for sound is created. Other things being equal, it is always desirable to preserve normal anatomic relations, but things are not always equal, and there are times when the fenestration operation is both preferable and essential. Nonetheless, mobilization of the stapes is a rational procedure, and it would probably have been revived earlier except for the conviction, still held in many quarters, that ankylosis of the stapes in the oval window is permanent and irreversible and that a direct attack upon the pathologic process would be futile.

A number of observers have stated the indications for mobilization of the stapes, none more lucidly than Kos,[3] who considers the indications and results, based on an experience of more than 400 cases, in four categories:

1. When bone conduction is normal and the air conduction loss is more than 35 db., stapedial mobilization is likely to result in practical, functional hearing in 30% to 40% of the patients. In this category, the only one in which comparison of the two procedures is valid, fenestration will achieve 60% to 80% of successes. On the other hand, before deciding upon his procedure, the otologist must remember that, while the fenestration operation is apparently about twice as successful as the mobilization operation in this group of cases, at least a third of the patients in it will not need the more difficult and dangerous operation if the simpler procedure is employed first.

2. When bone conduction is normal and the air-conduction loss is 35 db. or less, about 50% of the patients will be appreciably improved after mobilization.

3. When the bone-conduction loss is not below the level of 30 db. and the additional air-conduction loss is at least 20 to 25 db., about 30% of the patients will have a hearing level of 30 db. or better after mobilization and about half will have an improvement equal to the preoperative bone-conduction thresholds. In neither this group nor the preceding group does fenestration offer any such improvement.

4. When the bone-conduction loss is greater than 30 db. and the minimum additional air-conduction loss is 20 to 25 db., neither operation will restore practical hearing, but the mobilization operation will produce an improvement of 15 db. or more in about half of the patients, who will thus be able to wear hearing aids more effectively.

My own experience, in about 75 mobilization operations, generally bears out Kos' categories of results. I am also inclined to agree with Scheer [4] that fairly definite prognostications of success may be based on the following observations:

1. When the Rinne test is negative with the 512 fork but is still equal with the 1024 fork, the stapes is not likely to be completely fixed and can usually be mobilized. The highest percentage of good results is achieved in this category.

2. When both 512 and 1024 forks produce a negative Rinne test and the patient is still able to hear a moderately loud

voice, the stapes is likely to be firmly fixed but it can often be mobilized.

3. When both 512 and 1024 tuning forks produce a negative Rinne test and the patient has difficulty in hearing even a very loud voice, the stapes will probably be too firmly fixed to be mobilized at all.

Generally speaking, results are likely to be better in younger persons with a shorter duration of deafness than in older persons with a longer duration, regardless of the category of hearing loss. On the other hand, all of us have had the experience of encountering notable rigidity of the stapes, and achieving correspondingly less successful results, in young patients whose duration of hearing loss has been relatively brief.

Technique

Before describing the technique of mobilization of the stapes, one very essential consideration should be emphasized, that operations of this kind should be performed only by otologic surgeons who have been properly trained in endoaural surgery. Rosen's [1] criterion, that even a skilled surgeon should not undertake stapes mobilization until he has done it on at least 50 fresh cadavers, is somewhat unrealistic, in view of the difficulty of procuring cadavers today, but the reasoning is sound; the anatomic variations possible in this region demand a very precise knowledge before one begins to maneuver in it. One must learn to do the operation skilfully within the limited space of the external auditory canal, which is often tortuous as well as narrow. Mobilization of the stapes may seem deceptively simple, but in reality it is not simple at all, and there is no doubt that some unsuccessful results are due to its performance by surgeons who have not had sufficient practice on the cadaver.

A good many variations of the original Rosen technique [1,2] have been introduced, and I have tried most of them, but not for very long. I dislike and fear any operation which requires a direct attack upon the footplate. Damage to this delicate structure may end in labyrinthitis, with complete loss of hearing. The original Rosen technique avoids this risk, and I propose to continue to use it until a better one is devised.

The steps of the operation are as follows:

Thirty minutes before the procedure is started, the patient is given 2 to 3 grains (0.12 to 0.20 gm.) of phenobarbital sodium (Luminal sodium) and ⅛ grain (20 mg.) of Pantopon (a mixture of the hydrochlorides of the opium alkaloids) or 50 mg. of meperidine (Demerol) hydrochloride. Anesthesia is secured by the injection of lidocaine (Xylocaine) hydrochloride and epinephrine chloride (3:1) into the soft tissue external to the junction of the temporal bone and the cartilage. The solution is injected in 0.5 cc. amounts posteriorly, inferiorly, and superiorly.

Operation is performed through an ordinary aural speculum, with the aid of a Zeiss binocular loupe and the Storz headlight with a spot bulb. A petrolatum preparation is applied to the hair to hold it away from the auricle.

The incision, made through the skin over the bony canal, is begun posterosuperiorly at the point of junction of the pars flaccida and pars tensa of the drum. It is placed 6-7 mm. external to the drum. In the right ear, it extends from 11 to 5 o'clock and in the left ear from 1 to 7 o'clock.

The skin is separated from the bone as far as the drum, the separation beginning at the beginning of the incision. The drum is gradually lifted out of its sulcus; this maneuver is begun at the point of entry, which is a millimeter or two below the beginning of the incision. Eventually the drum is reflected upward upon itself, like an apron.

At this stage of the operation, the surgeon must bear in mind not only the normal regional anatomy but the possible variations. In more than 80% of all cases the major portion of the incudostapedial joint can be seen at this time, but visualization is not sufficient for either a satisfactory or a safe operation. The temptation to proceed with mobilization must therefore be resisted until from 2 to 3 mm. of the rim of the posterosuperior bony annulus, just external to the incus and stapes, has been removed. When this has been accomplished, one has a full view of the long process of the incus; the incudostapedial junction; the head, the neck, sometimes the crura, and the footplate of the stapes; the facial canal; the entire length of the stapedius tendon; the chorda tympani nerve; a portion of the incudomalleolar articulation; and the inner aspect of the hammer handle. All manipulations are now possible under full visualization.

The mobility of the footplate of the stapes is tested by placing a finely pointed probe against the

long process of the incus, close to its articulation with the stapes, and moving the instrument gently downward for a distance of about 0.5 mm. By watching the tendon of the stapedius, it can be determined at once whether or not the footplate is moving, since movement of the footplate is reflected in the tendon: The tendon moves in correspondence with the movement of the head and crura, which move, in turn, when the footplate moves. Movement can be felt as well as observed, and the surgeon's tactile sense must be capable of such perception before he can be said to have mastered the technique fully.

When conditions are normal and the footplate is freely movable in the oval window, the gentlest pressure of the probe against the long process of the incus causes free and unimpeded movement of all the structures. When the stapes is partly or incompletely fixed, greater pressure is necessary to move the structures even slightly, though again they move as a whole. When the stapes is completely fixed, very firm pressure of the probe against the long process of the incus causes only the incus to move. The rest of the structures show no movement at all.

When the stapes is fixed, pressure is exerted with the mobilizer on the anterior aspect of the neck, in line with the stapedius tendon, and is continued downward until mobilization is accomplished or until it is evident that it cannot be achieved. The pressure must be slow, firm, and applied intermittently, for not more than five to seven seconds at a time. A very considerable degree of pressure can be exerted on the neck of the fixed stapes without fracturing the crura, but it must always be controlled, and the amount that can safely be applied must be learned by experience. If adhesions involving the ossicles or round window should be encountered, they are cut, as necessary.

At the conclusion of the operation, the drum and the attached skin of the external auditory canal are replaced in their normal anatomic positions.

Anyone who has performed the operation will agree with Rosen[1,2] concerning the pitfalls which must be avoided:

1. In the beginning, because of the bulge of the bony canal wall, it may be difficult to separate the skin and lift the drum out of its sulcus anteriorly without damaging either skin or drum.

2. When the incus and stapes are completely hidden by the posterior wall of the bony canal, as they sometimes are, great care must be exercised in removing the edge of the bony wall to expose the ossicles.

3. Great care must be taken not to separate the incudostapedial joint during mobilization of the stapes. The greatest danger of disarticulation is in the cases in which the incus overlies the posterior portion of the stapes. Fortunately, this position is relatively infrequent.

4. Great care must be taken not to dislocate the footplate of the stapes by too sudden or too great pressure against the neck. Scheer's[4] studies on the cadaver indicate that an unbelievable amount of force can be applied to the neck before the crura will snap, and the same observation presumably holds in applying pressure to a stapes firmly fixed by otosclerosis. This margin of safety, however, exists only if the mobilizer is correctly placed on the neck.

All of these pitfalls can be avoided if the proper care is taken, but, as Rosen points out, they should be discovered on the cadaver and not on the human subject.

Present Status of Mobilization

Mobilization of the stapes has certain advantages which it is fair to emphasize:

1. It is a relatively minor operation, which can be performed under local anesthesia, within 35 to 45 minutes. The fenestration operation is best performed under a general anesthetic and cannot be done in less than an hour and a half, while it sometimes takes considerably longer.

2. The mobilization operation is not associated with shock, and, if vertigo does occur, its duration is brief. The fenestration operation is sometimes associated with serious postoperative vertigo and disequilibrium.

3. Surgical aftercare is simple with the mobilization operation. All that is necessary is removal of the dressing on the fourth or fifth day. The skin of the canal and the drum are red and swollen at this time, but healing is prompt, and within two weeks the surgical field usually looks entirely normal. When healing is complete, the tympanic membrane occasionally appears slightly retracted, but no scar is visible.

The simplicity of postoperative care after the mobilization operation is in marked contrast to the aftercare in the fenestration procedure. Repeated dressings are required, and even after the patient is discharged he must continue under observation and report for examination at least every six months.

4. After the mobilization operation, the patient may be ambulatory at once. He is permitted his usual diet. He may leave the hospital within 24 hours and may return to work within a few days. When once the incision has healed, he may swim, dive, and travel by air, as he wishes. The patient who has undergone a fenestration operation must be hospitalized for seven days or longer and can seldom return to work under four weeks.

One of the great advantages of the stapes operation is that if it is unsuccessful originally or if the original gain is not maintained, it may be repeated with impunity, more than once if necessary, and with a 50% chance, or more, of restoring the improvement once achieved. In some of the cases reported by Miot in 1890, the same ear had been operated on three times within a few months.

It is also possible, as has already been mentioned, to perform fenestration after unsuccessful mobilization. No difficulties are likely to arise if the tympanic membrane is intact and if the operation is deferred until the skin of the external auditory canal is completely healed. The number of recorded cases is still limited and no generalizations are possible, but my own experience, in five cases, permits me to say that failure in the first operation does not militate against success in the second. Rosen[1] reasons that if the percentage of successful mobilizations approaches or exceeds the percentage of successful fenestrations, it should be possible to offer mobilization as the first procedure to all patients with otosclerosis.

A certain psychologic factor must, of course, be considered if this practice is followed. The deafened patient is usually a depressed patient, and he does not tolerate failure well. If one operation fails, it may be difficult to gain his consent to another. Some otologists overcome this difficulty by telling the patient that the mobilization procedure is an exploratory operation. There is also a financial factor to be considered; some patients cannot afford the luxury of two surgical procedures. In such cases, I have made it a practice to tell the patient that if the mobilization operation fails, the amount paid for it will be applied against the fenestration operation. In a number of cases this has been a persuasive argument.

Postoperative complications, while they are not common, may occur after the mobilization procedure. They include labyrinthitis, facial paralysis, middle ear suppuration, and perforation of the tympanic membrane. Infection and perforation seldom alter the result, but labyrinthitis is quite another matter, as I know from my own experience in one very unfortunate case. I have also found that an upper respiratory infection after the mobilization operation depresses the hearing appreciably and may invalidate a good result.

It is still not clear why the mobilization operation is successful in some cases and fails in others. According to Rosen and Bergman,[2] there are three possible reasons for failure:

1. The footplate is so firmly fixed that it does not yield to pressure. In their opinion, this does not often happen.

2. The crura are so thin and fragile that they fracture, sometimes audibly, under the application of the force required to mobilize the footplate.

3. The technique is faulty. If the direction of force against the neck of the stapes is not in line with the crura, or if the force is mistakenly applied to these bones, which are thin and delicate, instead of to the neck, which is thick, crural fracture may occur.

May I add a fourth—the degree and extent of otosclerotic involvement.

Even with failure, however, the result is not a disaster, for, as already pointed out, the mobilization operation may be re-

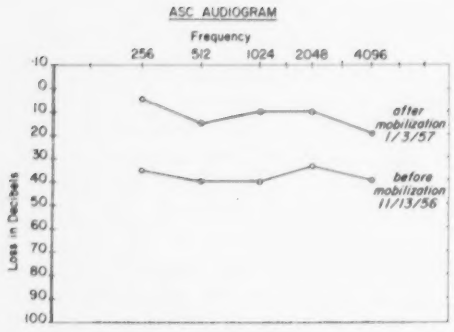

Fig. 1.—Sustained improvement after mobilization operation on right ear.

peated and the fenestration operation is still possible without penalty.

Rosen considers it remarkable that the fractured otosclerotic bone does not promptly begin to heal and ankylose the stapes again. It may be, as he suggests, that the otosclerotic focus contains the kind of bone which, when fractured, does not heal, just as fractures through the labyrinthine capsule frequently do not heal. This viewpoint is in line with that of Basek and Fowler,[5] who point out that one reason for permanent mobility of the stapes after operation may be the tendency of fractures of the footplate to heal by fibrous rather than bony union. It is, however, in contrast to Lempert's[6] idea that the otosclerotic lesion is a highly vascular osteofibrotic growth which, when injured, tends to regenerate rapidly.

Rosen's first articles on mobilization of the stapes were published in 1955. Lempert's fenestration technique was published in 1941. At the Eye, Ear, Nose and Throat Hospital in New Orleans, 41 fenestration operations were done in 1954. In 1955, there were 49 fenestrations and 58 mobilizations of the stapes. In 1956, there were 19 fenestrations and 88 stapes operations. In the first three months of 1957 there was 1 fenestration operation against 14 mobiliza-

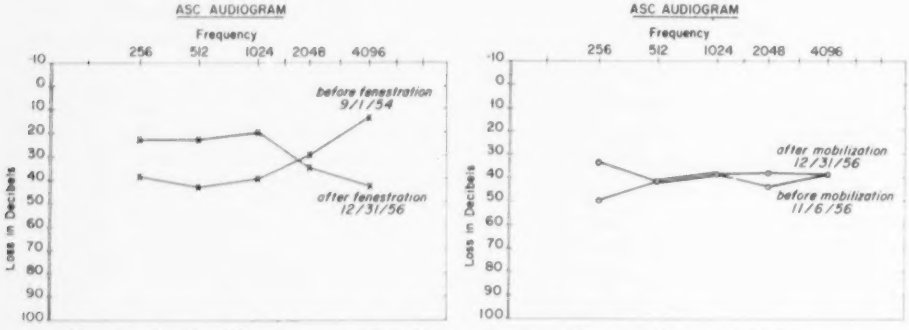

Fig. 2.—Sustained improvement after fenestration operation on left ear. Initial improvement, evident at mobilization operation on right ear, had disappeared six weeks later.

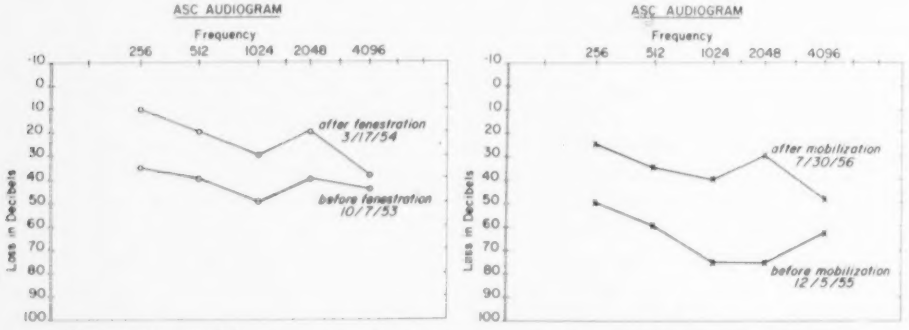

Fig. 3.—Sustained improvement after fenestration operation on right ear and mobilization operation on left ear.

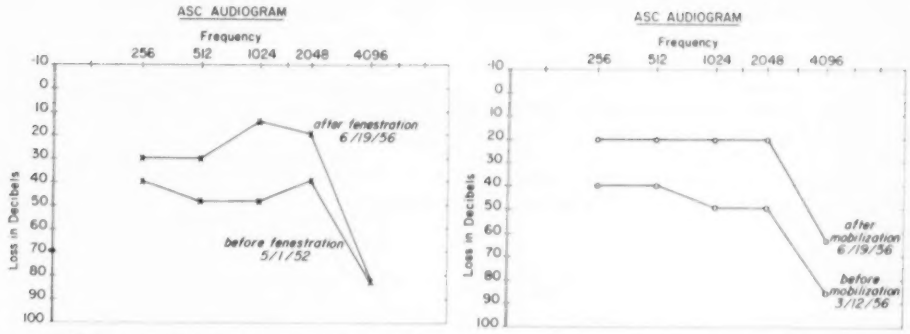

Fig. 4.—Sustained improvement after fenestration operation on left ear and mobilization operation on right ear.

tions of the stapes. Obviously, the new operation is extremely popular; I have done 75 of these stapes operations myself, with satisfactory to excellent results in about 40% (Fig. 1). I have, however, by no means abandoned the fenestration operation. It remains a useful procedure in the selected cases in which it is indicated, either alone or in combination with the mobilization operation (Figs. 2-4), and it is sometimes useful to correct the failure of operation on the stapes (Fig. 5). The mobilization operation has been in use too short a time to permit categoric statements about its value. Certainly it is too soon to say that it is the full answer to otosclerotic deafness. There is no doubt, however, that with its introduction or, more correctly, its revival, a valuable weapon has been added to the otologist's resources.

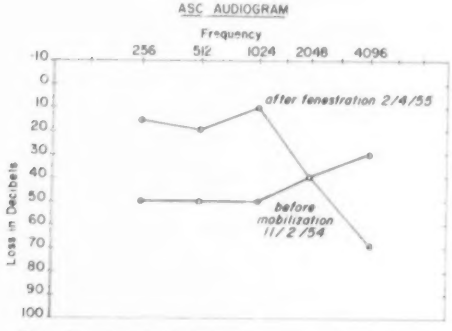
ASC AUDIOGRAM
Frequency
256 512 1024 2048 4096
-10 0 10 20 30 40 50 60 70 80 90 100
Loss in Decibels
after fenestration 2/4/55
before mobilization 11/2/54

Fig. 5.—Sustained improvement after fenestration operation on right ear following unsuccessful mobilization operation on same ear three months earlier.

Summary and Conclusions

Surgical mobilization of the ankylosed stapes has sound rationale behind it in that it attacks directly the pathologic process responsible for otosclerotic deafness. It is not a substitute for the fenestration operation, and comparison of the two procedures is not valid. Fenestration can be performed without jeopardizing its chances of success if the mobilization operation fails or if the improvement secured by it is not maintained. The patient's best interests are therefore often served by a preliminary trial of the simpler operation before fenestration is resorted to.

The original Rosen technique is superior to the modifications which have been suggested for it. This is not a procedure which should be attempted by any surgeon who has not had a careful training in it. The required aftercare is minimal, and the patient can return to work within a few days.

Although mobilization of the stapes is still on trial, because it has been employed for such a short time, there is no doubt of its usefulness and value at this stage of otologic progress.

921 Canal St. (16).

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The Problem of Permeability and Anesthesia of the Tympanic Membrane

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Use of drops in the external ear canal for relief of pain, myringotomy, or even in the treatment of nonperforating otitis media is based mainly on empiricism. Investigation of the value of such therapy is indicated.

The solution of these problems resolves itself into proving whether there is permeability of the tympanic membrane. The purpose of this study, is to discuss factors governing permeability in general, with the specific objective of scrutinizing topical anesthetics used on the eardrum.

A review of the literature[1,2] attests to these important facts: First, local anesthetics for all practical purposes can be considered as not being absorbed from intact skin (which does form part of the eardrum)[3,4]; second, very little has been proved about permeability of membrane,[5] and, third, papers in medical journals on anesthesia of the eardrum are rare.

Comparative Thickness of Eardrum and Permeable Membranes

Most permeability studies[5] have been made with single cells surrounded by membranes a few molecules thick (0.00001 cm. or one ten-thousandth of the depth of the tympanic membrane). Single cells most frequently studied have been erythrocytes, yeast, marine eggs, and bacteria.

Permeability has been observed in experiments with tissues such as muscle, nerve, and even more complicated structures[6] such as capillaries, alveoli, intestinal villi, the submaxillary gland, and the cornea.

It is interesting to note that the cornea, though 5 to 10 times as thick as the eardrum, is permeable.[7,8]

Whereas the cornea[9] measures 0.95 mm. deep in the center and 1.2 mm. in the periphery, the eardrum measures only 0.1 mm.[10] Although the pars tensa of the tympanic membrane is only 0.1 mm. (100μ) thick, the pars flaccida is even less deep, consisting of a cutaneous layer of 50 to 60μ and a mucosal layer of 20 to 40μ.[11]

These comparative measurements of the thickness of the cornea and eardrum are given because their histologic structures are similar to the extent that permeability results obtained from the cornea may be put to practical use in experiments with the tympanic membrane.

Quite as interesting is the similarity between the nerve distribution in the cornea and that in the tympanic membrane, first described by Jacques.[12] The resemblance was so striking to Wilson[13] that he said, "One is tempted to carry the analogy further and to say that as in the cornea pain and not touch appears to be the sensation evoked, so also in the membrana tympani one might expect that the slightest pressure would evoke unpleasant sensations, passing into pain, a fact well borne out by clinical observations."

Whether slight variation in the same type of cell, such as water content and position necessary for transparency of the cornea, affects disproportionately the degree of permeability has not been determined. If true, then permeability results found in experiments with squamous epithelium of the cornea may not be applicable to squamous

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epithelium of the eardrum, squamous epithelium being the real obstacle to permeation.

That squamous epithelium of the eardrum is the barrier to effective topical anesthesia is apparent to otolaryngologists experiencing poor anesthesia of the drum with cocaine but rapid, and too often toxic, penetration of cocaine into nonsquamous mucosa of the respiratory or the digestive tract.

To illustrate the confusion existing in the problem of permeation, one study[14] showed that some compounds soluble in both water and fat (biphasic) penetrate the cornea more readily when the overlying epithelium is intact than when it is removed.

Cellular Factors Affecting Permeation

All cell membranes, including squamous epithelium, have three sites of resistance[15]; first, water-membrane or water-lipoid; second, interior of the membrane or water, and, third, membrane-water or lipoid-water.

These cellular factors are pointed out to show that in order for a compound to penetrate a membrane physiologically it must be soluble in both fat and water. (Biphasic or balanced polar-nonpolar compound or compound with a high oil-water partition coefficient are all terms used to designate a compound soluble in both water [polar] and fat [nonpolar].[16]

Chemical Action of Physiologic Penetrating Compounds

During tissue permeation each polar group (e. g., OH, COOH) forms one hydrogen bond with water. To enter fat, each of these hydrogen bonds must be broken simultaneously. It is apparent that less kinetic energy is involved, and greater penetration of fat occurs with molecules with the least number of OH groups.

During tissue permeation all nonpolar groups (e. g., CH_3, C_2H_5) must rupture from fat at the same time when the molecule passes into the water phase. Again it is evident that greater penetration of water results with molecules with the least number of CH_3 groups.

To summarize,[15] molecules with few polar and few nonpolar groups should penetrate physiologically much more rapidly than molecules predominantly polar, predominantly nonpolar, or with many polar and nonpolar groups, resulting in an increase in molecular size and necessitating greater kinetic energy for passage through a membrane.

Physiologists[17] agree that some substances may penetrate by being assimilated into the substance of the cell.

This theory of permeability increasing with a decrease in molecular size is not sustained by toxicity studies[18] on local anesthetics showing that the anesthetic power of a homologous series increases with the molecular weight.

However, complex organic molecules contain portions relatively polar (water-soluble, hydrophilic) and portions relatively nonpolar (fat-soluble, hydrophobic). Perhaps compounds of decreasing molecular size diffuse rapidly through intermolecular spaces of tissue and large compounds balanced between polar and nonpolar structures penetrate slowly by assimilation into the cells.

Procaine, butacaine (Butyn), and tetracaine (Pontocaine) support the biphasic theory in that they are all *p*-aminobenzoic acid esters[8,19] but the procaine molecule (least active) is all polar, butacaine (more active) is the procaine molecule with one end slightly nonpolar, and tetracaine (most active) is the procaine molecule with one end polar and the other end nonpolar.

Therefore, the ideal physiologic local anesthetic appears to be a balanced polar-nonpolar compound consisting of the following[20]:

1. A lipophilic, or anesthetic, portion (cyclic and heterocyclic hydrocarbon formations with a varying number of substituted isosteric groups) providing lipoid solubility.

2. An intermediate, or connecting, portion (ester or isosteric group).

3. A hydrophilic, or water-soluble, portion (an aminoalcohol or isosteric group).

Action of Destructive Penetrating Compounds

Overton[21] demonstrated for the first time that all cell membrances give preferential (destructive-type) permeability to lipoid-soluble (nonpolar) substances.

These nonpolar (fat-soluble, water-insoluble) compounds favor rapid destructive-type penetration, and their penetrating power may increase with an increase in the nonpolar part of the molecule (CH_3, C_2H_5, C_3H_7, etc.) in spite of an increase in size of the molecule.

Some nonpolar compounds, simple hydrocarbons such as benzene, naphthalene, and aniline,[22] have been used extensively for permeability studies, and aniline is used as a local anesthetic on the eardrum.[23] These simple organic compounds, aniline[23] (Gray's fluid), and phenol[24] (Bonain's solution), are toxic for human use and approach the point of destructive penetration.

Permeative Electrolytes

Among the most important weak electrolytes used in otolaryngology are the local anesthetics.[25]

That the free bases permeate cell membranes more readily than their salts was also first demonstrated by Overton.[21]

The free base (undissociated form) of weak organic electrolytes, being both fat- and water-soluble, should theoretically penetrate the tympanic membrane, while the salt (dissociated form), being only water-soluble, should not be able to pass the epithelial barrier.

That weak organic electrolytes of anesthetics are both fat- and water-soluble when in an undissociated or free-base form, and water-soluble only when dissociated or a salt, is illustrated by the following statistics on our most commonly used topical anesthetic:

The solubility of cocaine[25] is 0.17 part per 100 cc. of water and 9.5 parts per 100 cc. of fat (tributyrin), whereas that of cocaine hydrochloride is 252.0 parts per 100 cc. of water but only 0.002 part per 100 cc. of fat.

Undissociation of anesthetics (ester group) is effected by increasing the pH of these weak bases.

Potentiation of Action of Local Anesthetics

The potency of most local anesthetics can be increased by the addition of certain substances,[26] such as alkali,[8,34] potassium ions,[35] proteins, purine (caffeine, theobromine), dyes (methylene blue potentiating procaine), analgesic drugs (acetylsalicylic acid [aspirin], phenol esters), and epinephrine.

Mixing of anesthetics with others (e. g., quick-acting procaine and slow-acting tetracaine) does not lead to potentiation.[27]

Potentiation by alkalinization and by the addition of vasoconstrictive drugs is of practical therapeutic value.[28]

Alkalinization converts the salt into a base and can increase the potency of most local anesthetics two to four times.[29]

The dissolved free base of procaine[30] has six times the anesthetic power of the hydrochloride, but, unfortunately, the advantage of potentiation is lost because as soon as procaine is injected into tissues the hydrogen-ion concentration is adjusted by the buffer action of the electrolytes in the interstitial fluid.

It has been stated,[30] and numerous authors agree, that "if a precipitate forms the

Precipitate-base in bottom of vials, which must be shaken to suspend base in order for it to be effective as a local anesthetic.

TABLE 1.—*Analgesic Effectiveness of One Cubic Centimeter of Two Per Cent Tetracaine HCl in HOH (from Stock Bottle) in Ear Canal Thirty Minutes During Myringotomy*

Patient	Sex	Age	Otitis Media	Duration Disease, Days	Pain* During Myringotomy
W.B.	M	38	Secr.‡	12	+
H.O.†	M	41	Secr.	14	++
W.R.†	M	45	Secr.	30	++

* Promontory pain during myringotomy: none, 0; slight, +; moderate, ++; severe, +++.
† Controls (cf. Table 2).
‡ Secr. is an abbreviation for secretory.

base has little or no action as a topical anesthetic." With this I cannot agree. The precipitate formed must still be the active base. I believe the solution is inactive because it was not shaken immediately before use in order to suspend the base, or because too small a needle was used to draw the precipitate-base into the syringe.

To determine whether a solution with a precipitate base is effective, a number of experiments were performed (Tables 1 and 2).

Otitis media with effusion is the commonest condition requiring myringotomy.[31]

It is realized that myringotomy in secretory otitis media can be performed without too much discomfort[31-33] but touching the promontory does cause pain, and touching the promontory with the aspirating suction tip was my indication of the degree of pain experienced. A painless promontory is also a sign of complete permeation of the tympanic membrane by the anesthetic.

From these limited experiments, it appears that when tetracaine is mixed with sodium bicarbonate[34-36] the base precipitates readily but the solution as a whole remains as effective as the potent base.

Use of injected vasoconstrictors in potentiation was first demonstrated by Braun[37] in 1903. It was explained that by constricting blood vessels epinephrine delayed the absorption of the anesthetic, but potentiation[38] is also helped by the local anesthetic inhibiting an enzyme, amine oxidase, which oxidizes or destroys epinephrine in the body.

When not injected, but applied topically,[27,36] epinephrine does not appear to increase the efficiency of local anesthetics under certain experimental conditions, contrary to general clinical belief.

Ephedrine is not as effective as epinephrine in the potentiation of local anesthetics, but 0.1% ephedrine itself produces anesthesia[39] when injected. Five and ten per cent solutions of ephedrine do not anesthetize the rabbit's cornea.

Benzylephedrine[40] has, when injected, an anesthetic effect twice that of procaine.

Cinnamylephedrine[41] is about 10 times as potent a surface anesthetic as cocaine.

TABLE 2.—*Analgesic Effectiveness of One Cubic Centimeter of Two Per Cent Tetracaine HCl in HOH with Three Per Cent $NaHCO_3$ in Ear Canal Thirty Minutes During Myringotomy*

Patient	Sex	Age	Otitis Media	Duration Disease, Days	Pain* During Myringotomy	Tetracaine Mixture, Age in Days
D.W.	M	36	Secr.§	25	0	Fresh
C.O.	M	39	Secr.	30	0	Fresh
B.P.‡	M	8	Secr.	1086 known	0	Fresh
A.S.	M	57	Adh.§	292	++	3
H.O.†	M	41	Secr.	10	0	16
R.L.	F	35	Secr.	998	0	16
J.S.	M	47	Adh.	383	+++	21
R.R.	M	7	Secr.	14	0	25
C.F.	M	25	Secr.	21	0	44
D.J.	F	32	Secr.	9	+	62
W.R.†	M	45	Secr.	114	0	68
W.R.†	M	45	Secr.	486	0	146

* Promontory pain during myringotomy: none, 0; slight, +; moderate, ++; severe, +++.
† Controls (cf. Table 1).
‡ Controls (cf. Table 3).
§ Abbreviations are as follows: Secr., secretory; Adh., adhesive.

Permeative Ions

The smaller the ion[15] the greater the penetration, e. g., cation potassium more than sodium and anion chloride more than citrate.

Some ions,[30] such as potassium and magnesium, cause a blocking of conduction in nerve fibers.

Since potassium penetrates more readily than sodium and has a blocking effect on nerve conduction, it might be of some advantage to use potassium instead of sodium bicarbonate in converting the tetracaine salt into a base.

Potassium sulfate,[30] 1.8%, mixed with 2% procaine hydrochloride has been investigated and was found to cause rather severe tissue irritation when injected.

Cations, or positive-charged ions, of local anesthetics are absorbed to negative-charged substances such as charcoal and, it is believed, to negative-charged nerve cells.

The salts of local anesthetics ionize in a manner similar to that of electrolytes in aqueous solutions, and the degree of ionization is dependent on the particular base and acid forming the salt. The degree of dissociation is small.

Although ions appear to play some part in local anesthesia, clinically their significance is not impressive in view of the fact that the base is much more anesthetizing than its salt.

Wetting Agents as Catalysts in Permeation

Wetting agents or detergents reduce surface tension, allowing tissue penetration by some otherwise noneffective drugs.

Local anesthetic drugs themselves lower the surface tension of water.[30]

Benzalkonium (Zephiran) chloride[42] is one of the better known wetting agents. It is a mixture of high-molecular alkyldimethylbenzylammonium chlorides, with a high bactericidal action and the capacity to remove dirt, skin fats, and desquamating epithelium.

Benzalkonium chloride, being acidic, is compatible with the salt tetracaine hydrochloride.

TABLE 3.—*Analgesic Effectiveness of One Cubic Centimeter of Two Per Cent Tetracaine HCl in Alevaire in Ear Canal Thirty Minutes During Myringotomy*

Patient	Sex	Age	Otitis Media	Duration Disease, Days	Pain* during Myringotomy	Tetracaine-Alevaire Mixture, Age in Days
C.H.	M	37	Secr. (left ear)	120	0	Fresh
G.W.	M	55	Adh.	730+	0	3
C.H	M	37	Secr. (right ear)	127	0	7

* Promontory pain during myringotomy: none, 0; slight, +; moderate, ++; severe, +++.

A left myringotomy was performed on a white man, aged 72 years, for secretory otitis media, with 1 cc. of 8% tetracaine in a 1:1000 aqueous solution of benzalkonium. The patient had moderate pain.

Another wetting agent, superinone, is found in Alevaire, a mucolytic detergent aerosol containing the detergent superinone and sodium bicarbonate in a glycerin-aqueous vehicle.

Hyaluronidase in Permeation

That permeation may occur by assimilation into tissue cells or by passage through the intermolecular spaces of tissue cells has been discussed. The possibility of transportation through the intercellular canals will now be considered.

The canals of intercellular cement may be the most direct, and least harmful, route between the external auditory canal and middle ear.

The flow of liquids between cells appears to be inhibited by hyaluronic acid, a polysaccharide. Hyaluronic acid can be hydrolyzed by hyaluronidase so that fluids can pass through the canals of intercellular cement.

Onset of anesthesia is hastened both during infiltration[43] and topical use,[44] provided there is an adequate mechanical pressure,[45]

TABLE 4.—*Analgesic Effectiveness of Five-Tenths Cubic Centimeter of Two Per Cent Tetracaine HCl in HOH with Five-Tenths Cubic Centimeter of Fresh One Hundred Fifty Turbidity Reducing Units of Hyaluronidase (Wydase) in Ear Canal Thirty Minutes During Myringotomy*

Patient	Sex	Age	Otitis Media	Duration Disease, Days	Pain* During Myringotomy
E.A.	F	40	Secr.	14	0
F.P.	M	39	Secr.	15	0
W.G.	F	71	Secr.	30	+
E.G.	F	27	Secr.	33	+
N.S.	F	72	Secr.	50	+
S.P.	M	38	Acute purulent	5 hr.	+++
B.P.†	M	8	Secr.	1080 known	+ But more pain than tetracaine + $NaHCO_3$

* Promontory pain during myringotomy: none, 0; slight, +; moderate, ++; severe, +++.
† Control (cf. Table 2).

TABLE 5.—*Penetration of Methylene Blue Alone and with Hyaluronidase (Wydase) into Tympanic Membrane*

Patient	Sex	Age	Type Eardrum	Dye	Result in 30 Min.
M.M.	F	69	Fibrotic; moderate	1 cc. of 2% methylene blue (1 day old)	Dye removed. H_2O_2 irrigation. Penetration into eardrum and epithelium of ear canal.
G.T.	F	52	Normal	1 cc. of 2% methylene blue (5 days old) with 150 TRU of hyaluronidase (fresh)	Dye removed. H_2O_2 irrigation. Penetration into eardrum and epithelium of ear canal. No dye in middle ear.

which may or may not be present in drops filling the external auditory canal.

In 80 patients with either acute catarrhal or secretory otitis media, Hussarek [46] instilled a 2% tetracaine-epinephrine-hyaluronidase mixture and found the eardrum fully anesthetized in as little as 10 minutes.

There are distinct advantages in the use of dyes in studying permeability. The results are unequivocal, since the dye can be observed passing through the membrane, and the test is simple without any necessary complicated apparatus.

Methylene blue (methylthionine chloride) is soluble in both water and fat and has been used as a 2% solution on the skin.[29]

Methylene blue alone, and with hyaluronidase was used to determine the effect of the latter upon the penetration of a dye into the tympanic membrane.

On injection, hyaluronidase does not appear to affect the analgesia time when epinephrine is added to the anesthetic agent, and epinephrine does not affect the diffusion rate increase by hyaluronidase.[47]

Ascorbic acid and dihydroxymaleic acid [48] have a spreading effect in tissue.

Wetting Agents Versus Hyaluronidase

Although the action of wetting agents and hyaluronidase differs, the results may be similar. This similarity was shown in dental blocks [49] in a comparison between a synthetic wetting agent, alkylaryl polyether alcohol (Triton A-20), and hyaluronidase.

Permeability of Skin

Since local anesthetics are not readily absorbed from the intact skin,[20] which forms the outer layer of the eardrum, any suggestions in reference to increasing permeability of the skin should be of interest.

Basnayake and Sinclair [50] showed that the skin of rats deficient in essential fatty acids is abnormally permeable to water and toxic substances.

Triethanolamine is an organic base with the power of increasing penetration into water and oily substances, is relatively nontoxic,[52] and has some bacteriostatic action. Triethanolamine lowers surface tension.[29]

Triethanolamine [51] combines with fatty acids to form soap soluble not only in water but also in oil.

By combining with the fatty acids [50] in the skin, triethanolamine may aid the penetration of anesthetics and other liquids.

Dyes such as gentian violet, brilliant green, crystal violet, and fuchsin are hydrolyzed and become colorless in the presence of triethanolamine. By adding water the dye becomes apparent. Theoretically, it may be possible to use a colorless mixture of dye with triethanolamine to detect the presence of fluid (reappearance of color) in the middle ear.

Antihistaminic and Anticholinergic Drugs

The pharmacologic actions of local anesthetics and the antihistaminic and anticholinergic drugs are very similar,[53] with blocking activity at the myoneural junction.

The local anesthetic effect of the antihistamines experimentally [54] and on humans has been reported.[55]

A Chronologic History of Anesthesia of the Eardrum

History of anesthesia of the eardrum has been deferred until this time because the history is best viewed with some understanding of the anesthesia problem as it exists today.

In 1859, Scherzer [56] brought coca leaves from Lima, Peru, into Europe. Dr. Scherzer and others knew that these leaves caused anesthetizing sensations in the tongue.

In 1860, Albert Nieman [57] in Germany isolated the alkaloid cocaine in crystalline form from the leaves of Erythroxylon coca.

In 1868, Thomas Moréno y Maiz,[58] ex-chirurgien-en-chef de l'armée de Péron (Peru), queried, "Could one utilize it as a local anesthetic?"

On Sept. 15, 1884, Koller [59] reported his observations on the action of cocaine in the eyes of frogs and humans, and immediately thereafter cocaine became extensively used in both ophthalmology and otolaryngology.

Zaufel [56] was the first physician to use cocaine in otology. He admitted that even a 10% alcohol-cocaine solution did not anesthetize all eardrums, even though he first attempted to macerate the epidermis with a 5% sodium bicarbonate-glycerin solution. This report was presented before a meeting of the German Medical Society at Prague on Nov. 14, 1884, two months following Koller's first report.

In 1896, Bloch [56] of Freiburg reported to the German Otological Society in Nuremberg that he had no success with ethyl chloride anesthesia on the eardrum.

In 1898, Bonain [56,116] used a mixture of phenol, menthol, and cocaine to anesthetize the eardrum. Later, in 1907,[116] because of Braun's work,[37] he added epinephrine.

In 1902, at New Bedford, Mass., McAuliffe [61] reported failure in an attempt to devise a tip for spraying ethyl chloride on selected areas of the tympanic membrane. In other words, he was attempting to improve upon Bloch's experiment [56] of 1896.

McAuliffe [61] believed that the use of Gray's fluid of 5%-20% cocaine in equal parts of absolute alcohol and aniline oil, though effective, was too toxic.

McAuliffe [61] experimented for eight years with tubal injections of cocaine and came "to the conclusion that the eustachian tube is the only channel through which local anesthesia [of the eardrum] can be best obtained."

Recently, in 1947, Max Unger [62] announced a new method of cocainizing the tympanum via the Eustachian tube, but actually his methods were a repetition of McAuliffe's work in 1902.

In 1904, Neumann [63] anesthetized both the meatus and the tympanum by injecting Heidenbain's 1% cocaine-epinephrine (Suprarenin) solution beneath the periosteum of the upper wall of the external auditory canal about 0.5 to 1 cm. lateral to the osseous part.

In 1909, Tiefenthal and Berndt [56] recommended injection of a few drops of 5% or 10% cocaine-epinephrine mixture through the eardrum. (I believe this injection would cause as much discomfort as a myringotomy.)

In 1911, Albrecht [56] described a method of cataphoretic anesthesia of the eardrum.

In 1912, Denker [56] recommended use of a cocaine-epinephrine paste for anesthesia of the tympanic membrane.

In 1913, Blegvad [64] advised the use of salicylic acid instead of phenol because of lessened destructive action. Blegvad's solution consisted of equal parts of cocaine hydrochloride and salicylic acid and 2 parts of "rectified spirit." To this solution was added, "just prior to use, a little 1 percent [epinephrine] adrenaline."

In 1925, Stout [65] used a mixture of equal parts of menthol, phenol, clove oil, and alcohol, to which was added cocaine if a deeper anesthetic effect was desired. In other words, Stout replaced cocaine with clove oil in Bonain's solution.

In 1926, Sturm [66] reported on the use of clove oil added to Bonain's solution. It is interesting to note [29] that clove oil U. S. P. contains not less than 82% eugenol, an unsaturated aromatic phenol.

In 1930, Morsman and Sinamark [67] stated that they attempted to anesthetize the eardrum with a mixture of equal parts of cocaine, phenol, menthol, glycerin, and alco-

TABLE 6.—*Analgesic Effectiveness of One Cubic Centimeter of Eight Per Cent Tetracaine HCl in HOH with Twenty-Five Hundredths Per Cent $NaHCO_3$ in Ear Canal Thirty Minutes During Myringotomy*

Patient	Sex	Age	Otitis Media	Duration Disease, Days	Pain* During Myringotomy	Tetracaine Mixture, Age in Days
B.W.	M	68	Secr.	1275 known	0	Fresh
R.R.	M	24	Secr	41	0	7
C.M.	F	40	Secr.	1454 known	0	9
R.F.	M	8	Secr.	28	0	14
G.B.	M	46	Secr.	62	0	19

* Promontory pain during myringotomy: none, 0; slight, +; moderate, ++; severe, +++.

hol but that it was not reliable. Apparently they added glycerin to Bonain's solution.

In 1934, Freystadtl [73] reported an attempt at quantitative measurement of surface anesthesia; he obtained painless myringotomy with an 8% watery solution of tetracaine against the eardrum for 20 minutes.

In 1935, Mangabeira-Albernaz [114,115] concluded that Bonain's solution is more effective when tetracaine is substituted for cocaine and recommended the following:

Glycerine	2 cc.
Tetracaine, Phenol crystals, Menthol	aa 1 gm.

The effectiveness of Bonain's solution during the past 58 years is attested to by the fact that it is probably the commonest anesthetic used on the eardrum today.[32,60,68]

New Surface Anesthetics

Local anesthetics [26] are usually divided into three large groups: alcohols, esters, and a miscellaneous group, which is of no practical interest at this time.

The alcohol group contains both aromatic and aliphatic alcohols which are neutral or acid and moderately soluble in water, such as phenol, menthol, and benzyl alcohol. With these alcohols (e. g., Bonain's solution) irreversible destructive changes tend to occur in the tympanic membrane.

The ester group has already been discussed in detail and contains benzoic acid esters (such as cocaine) and *p*-aminobenzoic acid esters (such as procaine, butacaine, and tetracaine). With these esters physiologic permeability occurs in that the permeating substance maintains its molecular integrity when effective in the middle ear and does this without any serious damage to the eardrum.

Although Bonain's solution is an effective eardrum anesthetic, it is time that such a destructive-type anesthetic be replaced by a more physiological one.

The chemist can synthesize a vast number of local anesthetic drugs, but there are only a few more effective than cocaine [69] topically.

A review of the literature was made on the following drugs: phenacaine (Holocaine), acoine, methyl *m*-amino *p*-hydroxybenzoic acid (Orthoform), a saturated aqueous solution of acetone-chloroform (Aneson), Orthoform New, hydrochloride of the diethylglycocoll derivative of methyl *p*-amino-*o*-hydroxybenzoate (Nirvanine), ethylaminobenzoate (Anesthesin), *p*-phenolsulfonate of ethylaminobenzoate (Subcutin), *p*-aminobenzoic acid propyl ester (Propaesin), isobutyl *p*-aminobenzoate (Cycloform), Erythrofleine, quinine, bimuriatic carbamidate, cocaine tartrate (Psicaine), the hydrochloride *p*-aminobenzoyl-dimethylaminomethyl-butanol (Tutocaine), butacaine sulfate, hydrochloride of benzoxy-dimethylamino-methyl-dimethylaminobutane (Alypin), *p*-aminobenzoyl-2,2-dimethyl-3-diethylaminopropanol hydrochloride (Larocaine), hydroxyprocaine, propoxycaine (Ravocaine), tetracaine, dibucaine (Nupercaine), lidocaine (Xylocaine), butethamine (Monocaine), WIN 4510 (an experimental drug), piperocaine (Metycaine), 2-isobutyl-aminoethyl *m*-aminobenzoate (Unacaine), brand of pipethocaine (Lucaine), 2(N-piperidyl)-ethyl *p*-propoxyphenyl ketone (Falicaine), hexylcaine (Cyclaine), β-diethylaminoethyl-*p*-ethoxy-benzoate (Intracaine), Bonocaine G Bitrate, dimethisoquin (Quotane), and even procaine crystals.[70]

Of these drugs for possible use on the eardrum, only tetracaine, dibucaine, Fali-

caine, dimethisoquin, and WIN 4510 appeared to be more potent than cocaine.

WIN 4510[71] has been discontinued by the manufacturer because clinical investigation[72] "revealed that the anesthesia was not sufficiently predictable to make the compound clinically acceptable."[72]

Dimethisoquin, dibucaine, and Falicaine are more potent than cocaine on animal corneas, and in the following ratios: cocaine being 1, dimethisoquin 1320:1, dibucaine 132:1, and Falicaine 10:1. I feel that additional animal experimentation is needed before clinical trial can be safely made with these toxic drugs on the human tympanic membrane.

Tetracaine, being familiar to all otolaryngologists, biphasic, more potent than cocaine, easily acquired, and already used on the eardrum,[46,73] appears to be the anesthetic of choice at this time.

Action of Local Anesthetics on Nerve Tissue

1. Meyer-Overton theory[21]: Local anesthetics are more soluble in fatty nerve tissue than in the surrounding tissues and fluid.

2. Metabolism theory[83-85]: Local anesthetics block the intracellular oxidation enzymes at the cytochrome-C-cytochrome oxidase level.

3. Humoral theory[86]: Local anesthetics, like curare, compete for receptors of a humoral transmitter, perhaps acetylcholine, responsible for the transmission of the nerve impulse.

4. Enzymatic theory[87]: Local anesthetics, being similar to acetylcholine, compete for the catalytic enzyme responsible for acetylcholine reacting with phosphocreatine. The adenyl phosphate released together with additional acetylcholine results in a chain reaction and the conduction of a nerve impulse.

5. Ionic theory[88,89]: Local anesthetics prevent migration through the neural plasma membrane of the permeable ions necessary for the conduction of an impulse. During the conduction of a nerve impulse sodium ions enter the nerve but potassium ions cannot immediately pass out, so that the interior of the nerve bears a positive electric charge compared with the exterior of the nerve. At this point the positive-charged ions of local anesthetics may be absorbed to the comparatively negative externally charged nerve cells.

Innervation of Tympanic Membrane

The tympanic membrane is supplied in its anterior outer portion[90] by the auriculotemporal branch of the trigeminal and in its posterior outer portion by the auricular branch of the vagus (Arnold's nerve).

The auriculotemporal branch and Arnold's nerve enter the external auditory canal[91] at the cartilaginous and osseous junction.

The medial surface of the eardrum is innervated by a few fibers from the tympanic plexus. The main trunk[92] of the

TABLE 7.—*Relative Potencies of Topical Anesthetics Considered Potentially Capable of Penetrating Eardrum*

Author	Tissue	Drug								
		Cocaine	Tetracaine	Dibucaine	Hexylcaine	Lidocaine	Propoxycaine	Falicaine	Dimethisoquin	Win 4510
Hamilton[74]	Cornea	1.0	8.8	132.0						
Ireland[75]	Trachea: animals	1.0	5.0							
Stark[76]	Endoscopic	1.0			1.0					
Cooper[77]	General discussion		1.0			0.5				
Southworth[78]	General discussion		4.0			2.0				
Crawford[80]	General discussion	1.0					1.5			
Gray[79]	Cornea: rabbit	1.0						10.0		
Gray[96]										
Anderson[81]										
Orkin[82]	General discussion	1.0			2.0+					
Gray[79]	Cornea: experimental			1.0					10.0	
Luduena[71]	Cornea: rabbit	1.0								10,000+
Mongar[111]	Skin Blister: human	2.5	34.5	32.8		2.3				
Steinhaus[76]	General discussion	3.0	8.0	20.0						

tympanic plexus is Jacobson's nerve, arising from the glossopharyngeal.

Sympathetic fibers from the carotid sympathetic plexus[92] anastomose with Jacobson's nerve anteriorly in the tympanum.

There is some doubt about the existence of sensory fibers from the facial nerve reaching the tympanic membrane through the geniculate ganglion.[93,94]

Properties of Vehicle

Some aspects of our method of using vehicles appear wrong.

Usually in the preparation of a local anesthetic the salt, being more soluble in water, is placed in a watery vehicle and the base, being more soluble in fat, is dissolved in a lipoid or lipoid-like substance.

The above procedure results in competition between the vehicle and the tissue being anesthetized, with decreased potency and poor economy. Serious consideration should be given in the use of topical anesthesia to this competition between tissue and vehicle, or to a sort of reversed Meyer-Overton law, in that the anesthetic may be more attracted to the vehicle than to nerve tissue.

This reversed Meyer-Overton law might be expressed as

$$\text{vehicle partition coefficient} = \frac{\text{solubility in vehicle}}{\text{solubility in tissue}}$$

in which the anesthesia increases as the vehicle partition coefficient decreases, or as a topical anesthetic index in which the anesthesia becomes more effective as the index increases:

$$\text{topical anesthetic index} = \frac{\text{solubility in tissue}}{\text{solubility in vehicle}}$$

There are clinical and experimental signs that the above thesis is true[95] in addition to confirmatory evidence given in this paper of the increased potency of tetracaine precipitate in watery solutions over tetracaine salt dissolved in solution.

Complications and Problems in the Use of Topical Anesthesia

Dangers may be encountered in the clinical or experimental use of topical anesthetics:

1. *Local Necrosis of Eardrum.*—Blegvad observed necrosis of the eardrum after use of Bonain's solution. I have used Bonain's solution for many years, filling the ear canal completely for 30 minutes, and have never witnessed any serious damage, but I feel that the hazard exists with all destructive-type solutions.[96]

2. *Vestibular Paralysis.*—Brown-Sequard[97] produced symptoms of labyrinthine paralysis by instillation of chloroform into the external auditory canal of guinea pigs.

Spiegel[97] was able to paralyze the labyrinths of cats, but not dogs or man, by electrophoresis of cocaine solutions from the external auditory meatus.

Vanderbeek[98] applied a pledget of cotton containing 2% dibucaine to a perforation in a tympanic membrane, and severe vertigo with rotatory nystagmus without deafness resulted.

3. *Cochlear Paralysis.*—After transtympanic injection of 2 cc. of 2% cocaine or 2% tetracaine, there is a drop in hearing of 30 to 40 db. lasting four to six weeks.[99]

Cocaine, 10%, placed on a perforated eardrum[98] caused a drop in hearing from 13.2%-78.5%, or a net loss of 65.3%, with final recovery.

The upper part of the tympanic membrane may not have developed, according to Ballenger,[99] resulting in a developmental perforation.

On the other hand, the eardrum of the newborn[100] compared with that of the adult is thicker and more resistant.

4. *Facial Paralysis.*—Facial paralysis has not been reported, but appears probable with a dehiscence of bone over the Fallopian canal.

5. *Inflammation.*—Inflammation causes an accumulation of acid in tissues with a lowered pH, and decreased susceptibility to local anesthetics (base converted into salt).[95]

During infection the permeability of membranes is altered.[101]

6. *Regeneration of Tissue.*—Aminobenzoates, 1%, do not appear to have any deleterious effect upon healing.

7. *Local Allergic Reaction.*—Contact dermatitis with cocaine and tetracaine does not appear to be common but is annoying, with itching as the earliest symptom.[102]

8. *Systemic Absorption with Allergic or Toxic Reaction.*—Although not as commonly used as Bonain's solution, Gray's fluid (90% aniline oil, 10% cocaine hydrochloride) is still used[103]; however, aniline poisoning has been observed.[64,68]

The fatal dose of aniline[113] for the human varies, but 0.1 to 0.25 gm. can cause alarming symptoms. Filling the ear canal with Gray's fluid equals approximately 0.9 gm. of aniline. Aniline is readily absorbed through the intact skin, and intoxication can occur from inhalation of the vapor.

The dose of 10% cocaine administered topically at one sitting[104] should not exceed 2 cc. The adult ear canal holds 1 cc., so that 1 cc. of 20% cocaine should be safe in an ear canal provided there is no perforation in the eardrum.

A fatal dose, rather than the speed of administration, determines overdosage.[105]

Methods for Detecting Permeability

Usual methods for detecting permeability are optical, chemical, and electrical.

A membrane is clamped between two tubes and the solution can be observed in its movement from one tube to the other (volume or dyes), analyzed chemically at intervals on either side or both sides of the membrane, or its action on the potential difference across the membrane can be measured.

Eardrum as a Testing Membrane

The tympanic membrane appears not too badly situated for permeability studies.

It may be tested in situ, thus there is no interference with its normal metabolism, as is so often necessary in most permeability experiments.

As far as the eardrum is concerned, it may not be necessary to use dyes, since fluid in the middle ear can be observed, although absence of fluid per se does not necessarily indicate nonpermeability.

Substances placed in the external ear canal but later irrigated from the middle ear by catheterization of the Eustachian tube or needle myringotomy[106,107] may be used to determine permeability curves.

Measuring the potential difference across the tympanic membrane may be technically difficult, necessitating insertion of an electrode through the Eustachian tube or through a subperiosteal tunnel in the external auditory canal.

Unique methods of determining permeability applicable only to the tympanic membrane may be, first, complaints of abnormal taste in the throat by the tested and permeable fluid escaping through a patent Eustachian tube[99]; second, anesthetizing effect upon functions of the chorda tympani nerve,[108] and, third, the depressed effect of the chemically laden permeant drum upon cochlear microphonics.

Methods for Testing Local Anesthetics

The human tongue[56] and the rabbit's eye[59] were first used to determine the effect of topical anesthesia.

The human-tongue method is very inaccurate, since the sensations of anesthesia and irritation are confused.

The cornea and frog skin[109] are considered dependable, but both are used to measure the ability of a compound to penetrate mucous membrane and not skin, as I had hoped.

The intradermal wheal[110] and the exposed dermis or blister[111] methods are not realistic for testing surface anesthetics.

The same painful stimulus in testing anesthesia of the eardrum should be used in all tests. I used as the painful irritant a cotton-tipped applicator before and after anesthesia, followed immediately by myringotomy with an aspirating suction tip placed against the promontory (promontory pain test to determine permeability of anesthesia through tympanic membrane).

TABLE 8.—*Sterility Tests of Analgesic Ear Solutions Used in Myringotomies (Solutions Stored in Ordinary Dropper Bottles at Room Temperature and Cultures Taken After Shaking Bottles Three Minutes)*

Solution	Age in Days	Organism Found*
Tetracaine, 2%, and $NaHCO_3$, 3%, in HOH	314	None
Tetracaine, 2%, in Alevaire	146	None
Tetracaine, 8%, and $NaHCO_3$, 0.25%, in HOH	46	None
Tetracaine, 8%, and aqueous benzalkonium, 1:1000	45	None
Cocaine alkaloid, 20%, and triethanolamine, 1%	29	None

* Cultures by Weeter Clinical Laboratory (M. L. Barnes, M.D., Director; A. J. Miller, M.D., Consultant).

In testing anesthesia of intracutaneous wheals Hoffmann and Kochman, in 1914, and later Sollmann,[112] in 1918, found cotton twisted to a fine point the most accurate stimulus.

Freystadtl,[73] 1934, in studying the penetrating capacity of different anesthetics on skin, found that the sensation of cold disappeared first, followed in order by the sensations of touch, pain, and heat. Cold and heat might possibly be used then in the external ear canal to determine quantitatively the intensity of anesthesia.

A blind test procedure with use of a nonanesthetic or weak anesthetic control by the experimenter is a requisite for significant results.

In testing anesthetics,[109] one should compare minimal dose giving anesthesia, speed of onset, depth, and duration of anesthesia. In addition, at a physiological hydrogen-ion concentration, the anesthetic must be able to penetrate the eardrum but with reversible action, cause no pain or harmful tissue reaction, and be both sterile and stable.

To determine the effect of a vehicle upon penetration of a drug through the tympanic membrane, both oily and watery vehicles should be added to the drug, whether polar, nonpolar, or balanced polar-nonpolar.

TABLE 9.—*Tetracaine Content* in Solutions Used for Anesthetizing Eardrums*

Solution	Age in Days	Before Shaking		After Shaking	
		Tetracaine Calc. as HCl	*p*-butylamino-Benzoic Acid	Tetracaine Calc. as HCl	*p*-butylamino-Benzoic Acid
Tetracaine 2%, and $NaHCO_3$, in HOH (20 mg/ml.)	335	5.79 mg/ml.	5.34 mg/ml.	5.89 mg/ml.	5.61 mg/ml.
Tetracaine, 2%, in Alevaire (20 mg/ml.)	167	4.28 mg/ml.	2.35 mg/ml.	5.49 mg/ml.	2.58 mg/ml.
Tetracaine, 8%, in aqueous benzalkonium, (80 mg/ml.)	50	73.20 mg/ml.	0.57 mg/ml.	71.56 mg/ml.	0.60 mg/ml.

* Analysis by Winthrop Laboratory (M. L. Tainter and D. Slevin).

Summary and Conclusions

Use of drops not only for otalgia but also in the treatment of nonperforating otitis media is frequent, expensive, and based mainly on empiricism.

TABLE 10.—*Summary of Myringotomy Results*

Solution	Sex		Age Range In Years	Duration of Disease, Range In Days	Pain* During Myringotomy, No. Patients											
					Secretory				Inflamed				Adhesive			
	F	M			0	+	++	+++	0	+	++	+++	0	+	++	+++
Tetracaine, 2%, in HOH		3	38-45	12-30		1	2									
Tetracaine, 2%, and $NaHCO_3$, 3%, in HOH	2	10	7-57	9-1086	9	1									1	1
Tetracaine, 2%, in Alevaire		3	37-55	120-730+	2								1			
Tetracaine, 2%, with 150 TRU hyaluronidase	4	3	8-72	5 hr.-1080+	2	4						1				
Tetracaine, 8%, and $NaHCO_3$, 0.25%	1	4	8-68	28-1454 known	5											
Tetracaine, 8%, in 1:1000 aqueous benzalkonium		1	72	32			1									
Total	7	24	7-72	5 hr.-1454 known	18	6	3					1	1		1	1

* Promontory pain during myringotomy: none, 0; slight, +; moderate, ++; severe, +++.

There is a need for experimental and clinical investigation of all factors affecting the penetration of drugs through the normal and the abnormal tympanic membrane.

Squamous epithelium is the real barrier to permeability of the eardrum.

All cell membranes have three sites of resistance: water membrane (lipoid), interior of the membrane (water), and membrane (lipoid) water.

A physiologic permeating compound must be both soluble in fat (lipophilic) and in water (hydrophilic). Such a substance is called biphasic, or a balanced polar-nonpolar compound.

The polar groups (e. g., OH, COOH) of physiologic penetrating compounds form hydrogen bonds with cellular water, and the nonpolar groups (e. g., CH_3, C_2H_5) combine with cellular fat. All these bonds must be broken simultaneously during tissue penetration, so that less kinetic energy is involved and greater penetration occurs with molecules with the least number of polar and nonpolar groups.

However, the theory that permeability increases with a decrease in molecular size is not sustained by toxicity studies showing that the anesthetic power of a homologous series of local anesthetics increases with molecular weight.

Local anesthetics are weak electrolytes. The free base (undissociated form) of weak organic electrolytes, being both fat- and water-soluble, should theoretically penetrate the tympanic membrane, while the salt (dissociated form), being only water-soluble, should not pass the epithelial barrier.

Most local anesthetics are used in a salt form because of cheapness and stability (Table 9). By converting the salt into a base with an increase in potency [29] of two to four times, potentiation by alkalinization appears to be of practical therapeutic value, with its first use in otology in the ear canals of guinea pigs by Ikebe [117,118] and on the tympanic membranes of humans by me (Tables 1, 2, and 6).

Whether the dissolved base alone or dissolved base plus precipitate base is responsible for the increased potency remains to be determined experimentally by separation of the two bases.

Otitis media with effusion is the commonest standard abnormal condition for testing anesthetization of the eardrum for myringotomy. Although myringotomy in secretory otitis media can be performed without too much discomfort, the promontory is painful, and a painless promontory is a sign of permeation of the tympanic membrane by the anesthetic without the use of elaborate equipment.

Salts of local anesthetics ionize in a manner similar to that of electrolytes in aqueous solutions. The degree of dissociation is small and is dependent on the particular base and acid forming the salt. Clinically, the significance of ionization is not impressive in view of the fact that the base is more anesthetizing than its salt.

The smaller the ion the greater the penetration, e. g., cation potassium more than sodium and anion chloride more than citrate.

Some ions, such as potassium and magnesium, cause a blocking of conduction in nerve fibers. Since potassium penetrates more readily than sodium and has a blocking effect on nerve conduction, it might be of some advantage to use potassium instead of sodium alkali in converting the tetracaine (Pontocaine) salt into a base.

Wetting agents or detergents reduce surface tension, allowing increased tissue penetration (Tables 1, 3, and 10). Local anesthetic drugs themselves lower the surface tension of water.

The canals of intercellular cement may be the most direct, and least harmful, route between the external auditory canal and middle ear. Hyaluronic acid, the inhibitor in intracellular cement, can be hydrolyzed so that fluids can pass through these canals (Tables 1, 4, and 10).

The pharmacologic action of local anesthetics and that of the antihistaminic and

anticholinergic drugs are similar, with blocking activity at the myoneural junction.

In reviewing a chronologic history of anesthesia of the eardrum, the effectiveness of Bonain's solution is attested to by the fact that it, or some modification, has been the commonest anesthetic used on the eardrum during the past 58 years. However, the empiric use of Bonain's solution reflects upon the lack of scientific investigation of this problem, and it is time that such a destructive-type anesthetic be replaced by a more physiological one. Bonain's solution is probably effective because it harms the epithelial barrier of the eardrum.

To determine the effect of a vehicle upon penetration of a drug through the tympanic membrane, both oily and watery vehicles should be added to the drug, whether polar, nonpolar, or balanced polar-nonpolar.

The following dangers may be encountered in the use of local anesthetics on the eardrum: local necrosis, vestibular and/or cochlear paralysis, facial paralysis, local allergic reaction, and systemic absorption with toxic or sensitivity reaction.

Inflammation causes an accumulation of acid in the tympanic membrane, with a lowered pH and decreased susceptibility to local anesthetics (base converted into salt) (cf. poor anesthesia in acute and chronic inflammatory otitis media in Tables 2, 4, and 10).

Unique methods of determining permeability applicable to the tympanic membrane may be, first, complaints of abnormal taste in the throat by the tested and permeable fluid escaping through a patent Eustachian tube; second, anesthetizing effect upon functions of the chorda tympani nerve, and, third, the depressed effect of the chemically laden permeant drum upon cochlear microphonics.

A standard stimulus should be used in testing anesthesia of the eardrum experimentally.

A blind test procedure with use of a nonanesthetic or weak anesthetic control by the experimenter is a requisite for significant results.

In testing topical anesthetics, one should compare minimal dose giving anesthesia, speed of onset, depth, and duration of anesthesia.

The ideal anesthesia, or any permeable drug, must be able to penetrate the eardrum but with reversible action, cause no pain or harmful tissue reaction, and be both sterile and stable at a physiological hydrogen-ion concentration.[119,120]

If used in a base form, tetracaine,[121] being familiar to all otolaryngologists, biphasic, more potent than cocaine, and easily acquired, appears to be the anesthetic of choice at this time for further experimental studies.

610-613 Brown Building (2).

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Intravascular Agglutination of the Blood

Major Factor in Otosclerosis, Ménière's Disease, Tinnitus, Vertigo; Neural Deafness—Total, Partial, Transitory, Recurrent, Progressive

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Intravascular agglutination or clumping of red blood cells can be easily observed within the blood vessels of the ocular conjunctiva with sufficient oblique illumination and 50× or more magnification. It is a very common phenomenon.

The clear-cut lumps or aggregates, known as "sludge," agglutinates, "masses," "red or white thrombi," are observed regularly circulating in the blood stream during acute, chronic, and progressive illness and in old age, not to mention severe trauma and burns. In addition, exposure to cold, a cut, a bruise, a slight burn, a word that shocks, or a conscious or an unconscious emotional thought, even the prick of a pin, can evoke some "sludging" of the blood.[1] Originally the researches of Knisely, Bloch, et al. stimulated my clinical curiosity, and I have examined all of my patients for "sludge" for over a decade. Recently the studies of Lars-Erik Gelin[2] have emphasized that slight injuries as well as the common types of fractures can produce anemia, a concomitant low blood count, and intravascular agglutination of the blood. My son, as well as many others, concurs with my belief that lumped blood may cause many clinical symptoms.[3,4] I show you electron micrographs of normal and sludging blood from the monograph of Prof. E. H. Bloch.[9] Note the differences in the edges of the cells (Figs. 1, 2, 3).

Since the beginning of my interest in the subject I have believed that agglutinates of one kind or another obstructing the smaller vascular channels of the auditory apparatus are involved in the causation of most sudden total permanent deafness, most sudden neural transient deafness, in the etiology of the bone dyscrasia known as otosclerosis, in Ménière's disease, and in many of the symptoms (especially tinnitus and vertigo) so often concomitant with such disorders. In my opinion no other explanation is as tenable in these otological entities of otherwise unknown origin. I set forth herein some observations supporting my opinion.

Many organic and chemical poisons not only act as protoplasmic poisons directly, but also indirectly, by causing local anoxia.

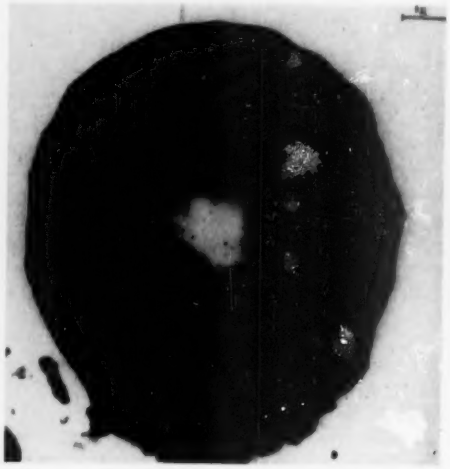

Fig. 1.—Electron micrograph of a human red blood cell obtained from a healthy circulation; reduced about ⅓ from mag. × 2000. Salt crystals are stuck to the lower border of the cell and can also be seen through the center portion. (Figs. 1, 2, and 3 from E. H. Bloch and A. Powell: Electron Microscopy of Human Erythrocytes from Healthy and Sludged Blood, Science 115:46-47, 1952, published by The American Association for the Advancement of Science, Washington, D. C.)

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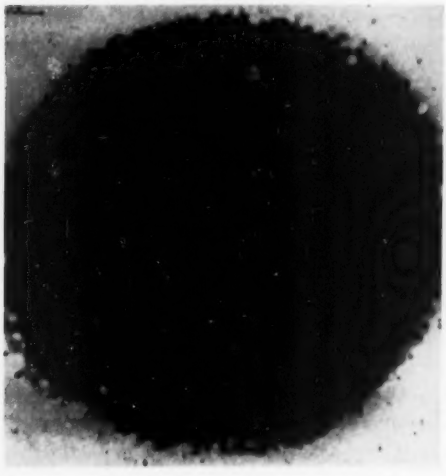
The local anoxia is basically brought about by blockage or stoppage of the blood flow which occurs with intravascular agglutination (microscopic and macroscopic). Degeneration, fibroplasia, bone dyscrasias, and atrophic states may result. Organs far from the site of the initial lesion causing or caused by sludging of the blood may be affected.

Hemagglutination in any area is in itself conducive to a local anoxia, and if of sufficient duration and degree will produce a lesion and eventually symptoms. Rest of body and mind with reestablishment of the circulation may lessen the anoxia and the symptoms by a return to the prevailing general and local environment existing before permanent damage has occurred.

When an initial trauma destroys in whole or in part a sense organ, the lesions engendered by the trauma are intrinsically dependent upon the local anoxia caused by the blocked circulation of the blood.

Anoxia, especially localized anoxia, is a major factor in disease of tissue, even when the genesis of the lesion appears to be mechanical, chemical, hormonal, or neural. Anoxia may be brought about by any sufficient local diminution in blood flow, blood oxygen, or blood oxygen exchange. All poisoning eventually produces anoxia, no matter what the instigating cause may be. Eventually and basically man and all animals die of anoxia.

Fig. 2.—Electron micrograph of a human red blood cell obtained from sludged blood (bronchopneumonia); reduced about ⅓ from mag. × 2000. Note total increase in diameter of cell because of the coating, as compared with healthy cell of Figure 1.



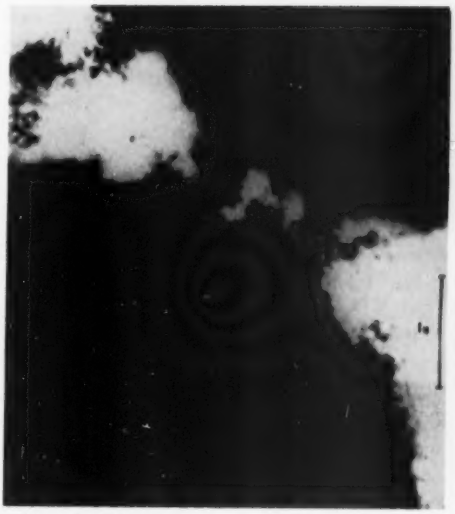


Fig. 3.—Electron micrograph showing coating between two human red cells from sludged blood; reduced about ⅓ from mag. × 5625.

Paradoxically, too much oxygen may, if prolonged, bring about local anoxia and a fibroplasia, as, for instance, in the premature "incubator baby." Too much oxygen literally burns up tissues so rapidly, especially certain vulnerable immature developing tissues, that metabolism is disrupted and fibroplasia and degeneration of the more highly sensitive elements occurs, i. e., retrolental fibroplasia, intralabyrinthine fibroplasia. In my opinion, such lesions may develop before as well as after birth. Nature has a way of reacting strongly to too much, as well as to too little.

As a cause of disease intravascular agglutination is of greater importance than extravascular coagulation (true clotting). Intravascular agglutination may occur even without any rupture or any detectable damage to the vascular channels and ofttimes may recur for long periods of time without recognizable disease.

It is not generally realized how much functional activity is lost when red blood cells stick together. When two red blood cells are stuck together (stacked), two of the surfaces will be apposed and smothered, and therefore 50% of their combined surfaces will be nonfunctioning. When three cells are stuck together, four of the surfaces will be apposed and smothered, and therefore 66.66% of their combined surfaces will be nonfunctioning. When 10 cells are stuck together, eight of the surfaces will be apposed and smothered, and therefore 80% of their combined surfaces will be nonfunctioning. When 100 cells are stuck together, 198 of the surfaces will be apposed and smothered, and therefore 98% of their combined surfaces will be nonfunctioning. When 200 cells are stuck together, 398 of the surfaces will be apposed and smothered, and 99% of their combined surfaces will be nonfunctioning, and therefore the oxygen supply normally available from this number of red cells will be cut down to about 1% or less.[5]

One hundred cells constitute a very small mass (less than 0.1 cu. mm.), but it is large in comparison with the caliber of the smaller arterioles, venules, and capillaries and arteriola capillary sphincters. These structures often in their normal functioning states have the caliber just sufficient to allow the passage of blood cells one at a time.

If the agglutinated cells are in irregular or rounded masses, they cannot be readily pushed through the arterioles and the arteriola capillary sphincters, in which event these vessels are clogged and the circulation stops until the masses are squeezed through the bottlenecks. In most situations permanent blockage occurs only occasionally, so in spite of the fact that the circulation may be "slowed" it usually is not stopped for long periods of time. A criterion for estimating the amount of local anoxia from such slowing and lumping is to determine the size and tenacity of the masses and the ease with which they are squeezed through the bottlenecks. Keep in mind that in the lesion itself there is more impedance to the blood flow and therefore more local anoxia than in the conjunctival vessels, which we use merely because fortunately they are in a location easily available for observing the peripheral blood flow.

The measurements of general hypoxia are misleading as a guide to local anoxia because they measure only the oxygen that has been obtained from the lungs and is passing through the lobe of the ear, or that contained in blood obtained from arteriolar or venous punctures. In other words, just because there often appears to be no dramatic hypoxia, or no recognized lowering of oxygen exchange, or no change in the color index of the circulating blood, this does not necessarily mean that a local anoxia in one or more organs or parts of organs does not exist.

Bear in mind that under low or medium loads most tissues require only medium availability of oxygen and that even severe oxygen hunger may produce no serious loss in function for some time.[6] An animal may live for a long time in apparently otherwise good health with almost a total lack of oxygen supply to several small nonvital areas of the body. There is a large margin of safety in over-all oxygen requirements under minimum or moderate levels of organ functioning (a large capacity to survive). However, eventually insufficient oxygen will produce symptoms such as fatigue, rapid or deeper respiration, increased blood pressure (for a time), and an increase and shift in erythrocytes; all of this in an effort to overcome the anoxemia—a strain, a super effort, to regain sufficient oxygen to preserve function and to preserve life.

Sludging blood cells tend to stick together in the form of long or short masses or clumps, and this clumping is a different process from that observed in true clotting, intra- or extravascular.[5] I can find no evidence in the literature that fibrin is present in intravascular agglutinates. However, it may be that although no fibrin is present, certain types of agglutination might be pro-

dromal to clot formation. The intravascular injection of thrombin does induce agglutination.[7]

Intravascular agglutination is involved in defense mechanisms. It is present in hypothermia, hibernation, allergies, and in all infections. In early stages of infection it probably plays a useful role because in the early stages the leukocytes are extruded from the masses into the blood stream, where they aid in furnishing a local concentration maybe sufficient to slow up or combat, at least temporarily, a lesion at its inception. This idea is suggested and supported by the fact that leukocytes line the walls of blood vessels as sludge is formed. How could they attain such an arrangement surrounding the sludged blood unless they came from the masses? In what other way could they so soon be present at the site of trouble? The blood stream being blocked, they could not reach it quickly through the general circulation; they could not have pushed their way along the narrow space remaining between the sludged blood and the vessel wall because this passageway would be blocked.

It is as yet not clear what happens to the interior of the red blood cells when they stick together, although it would seem certain that even when their hemoglobin is retained it is not functionally usable. Its availability for taking up and discharging oxygen is curtailed roughly in proportion to the amount of cell surface smothered. There results an increased hemoglobin concentration in the blocked areas but a decreased circulation of hemoglobin.

The diminished hemoglobin content of circulating sludging blood has been explained by the increase of the plasma volume. I believe it is explainable at least in part by the diminished capacity of the vessels due to their lumens being largely occupied by the aggregates. There is less space in the blood stream for those erythrocytes which are still functioning. There is, in spite of any relative increase in the number of blood cells packed into the smaller arterioles and capillaries, a dearth of oxygen, and since there are fewer red cells circulating, the plasma content of the larger vessels is increased.

It should be pointed out that intravascular coagulations totally smother the cells within the masses, and at least one-half of the cells on the surface of the masses. It should be stressed that they not only remove almost 100% of the functioning ability of the cells within the masses, but also occupy space in the blood stream that otherwise would be filled with functioning cells. Even if more erythrocytes were available because of an increased production, they would be unable to replace the loss because there would be little or no room for them in a blood stream (or capillary bed) largely occupied by the agglutinates. It might be contended that more cells could be crowded into the stream, but if crowding occurs the newly supplied erythrocytes too would tend to become agglutinated, because crowding causes more friction and therefore more slowing of the blood, especially in the smallest vessels, and more adhesion of leukocytes and platelets to vessel walls, all of which would be conducive to more intravascular agglutination.

It is well known that so-called "stress" may cause severe neurovascular reactions resulting in local anoxia. However, it has not always been clear just how the anoxia is prolonged because spasms in small vessels are not permanent. They are soon relieved by various means. The intravascular agglutinates always present with small vessel spasm explain the prolongation of anoxia after spasm has ceased.

"Stress" and "Strain"

A current opinion seems to be that "stress" is the cause of all evil. The word "stress" has been overstressed. It may be misleading and therefore harmful because stress is not in itself a bad thing; on the contrary, it is physiological and often beneficial. I dislike the word "stress" and prefer "strain," which implies overstress, or an overreaction, an overactivity or effort (men-

tal or physical) beyond safe or proper limits. Hard work (or even occasional overwork) is rarely in itself genetically sufficient to cause damage unless there are unfortunate overlays of anxiety or frustration factors involved, under which circumstances it becomes "strain."

According to the dictionary, strain also has other meanings such as an inherited quality or disposition. Strain also means to drip through, to squeeze, press, stretch, to worry. It may be the cause as well as the result of any severe striving or wearying effort or undue pressure (psychic or somatic).

I submit that the word "strain" better describes the pathophysiology than the word "stress."

"Strain" in its medical connotation is in no sense physiological; it is pathophysiological or pathological. Let us therefore abolish "stress" as a pathological entity and use instead the word "strain."

Since intravascular agglutination has been observed under sympathetic stimulation and epinephrine injections[8] we can assume that "strain" can produce plugging of vessels and thus real somatic symptoms as discussed in the first part of this paper.

Although intravascular aggregates are an important factor in the genesis of many diseases and disorders of many tissues and organs, I shall discuss herein only a few which are of otological importance.

In my opinion, a major factor involved in the genesis of otosclerosis in susceptible persons is an intravascular agglutination of the blood occasioned by repeated or continuing so-called "strains." I have found that a positive history of unresolved "frustrations," "abuses," "mental and bodily illness," "emotional hypersensitivity" is almost a *sine qua non* for the subsequent onset and increased symptomatology of an otospongiosis. Moreover, during the progressing (active) stages of otosclerosis, and also during attacks of Ménière's disease, sludging of the blood has invariably been observed by me. Confirmatively, my son, Edmund Jr., has demonstrated sludging of the blood in Ménière's disease and Ménièriform attacks induced by experimental as well as by natural psychic stimuli.[8]

Sometimes during the stabilized or inactive periods of both of these disorders little or no sludge may be seen, but it may be made to reappear or increase by even apparently trivial emotional repercussions. I have repeatedly produced this reaction.

During both transient and even continuing attacks of tinnitus and vertigo sludging of the blood is regularly marked, and in most otosclerotic patients blueness of the sclera of the eyeball increases transiently with the emotional episodes.

Blueness of the sclera is dependent upon the amount of blood in the uvea and the transparency of the sclera. I have found it in more than 60% of my patients having otosclerosis, including those in both the seemingly active and the inactive stages. I found it to be seven times that in the normal controls. Without exception I have observed marked sludging of the blood in every patient whom I examined soon after the sudden onset of a severe or total neural deafness. This strongly suggests that it was caused by a local anoxia in the auditory labyrinth due to blockage of the circulation.

Is it possible to do anything to diminish intravascular agglutination of the blood? Yes, I believe it is. I will mention first the management of the patient. It is of the utmost importance to talk to him and help him to become adjusted to his so-called "emotional instabilities," to give him a philosophy of living, of sickness, and of death, to imbue him with the necessity of "growing up" and facing facts, to persuade him to discontinue overwishful thinking and to adapt to disappointments and to frustrations—to live a satisfying life. (Aggravation causes aggregation.) Insist on a sensible diet, sufficient fluids, water, milk, greens, and proteins. Use medications cautiously

and with close supervision,[5] especially heparin, bishydroxycoumarin (Dicumarol), low-molecular dextran. The iodides and the hormones and mild sedatives are beneficial when indicated.

None of the powerful anticoagulant drugs such as heparin, bishydroxycoumarin, procaine, etc., can be used safely for long periods of time. They are most useful during the first few hours of the local anoxia caused by sludge. If they do not quickly act favorably they should be stopped. However, atropine, glyceryl trinitrate (nitroglycerin), nicotinic acid, and other dilators can be given for long periods. Limitation of space prevents me from going further into these matters at this time.

If we are to be of service, there is one thing that should be done, especially in persons subject to hereditary diseases associated with sludging. Examine them early and regularly for intravascular agglutination. If a tendency to sludging is discovered, take measures to lessen it; it is a sign of impending trouble.

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The Evolutionary History of Man from the Evidence of the Nose and Larynx

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Introduction

The upper respiratory passages are of the utmost importance in the mammalian economy, since the freedom of passage of air through them is a determining factor in all bodily activity. Although only the nose and larynx are cited in the title of this communication, yet it is impossible to refer to them without considering the intervening channels and also the lower respiratory tract; since in man the pharynx is capacious, forming part of the upper air passage and since the mouth of the esophagus is in close relationship to the larynx and is associated with it in the mechanism of swallowing, the present inquiry will extend itself to cover a wide subject.

Not only in relation to vital bodily processes, but also in directing activity, the nose and larynx are extremely important; the former has the function of distinguishing between foods and of giving aesthetic pleasure, while the larynx affords the means of intercommunication and of exchange of ideas.

Anatomical Basis of This Inquiry

There is sometimes a tendency to consider man as on a separate anatomical and physiological plane from other members of the animal world; that view will not be adopted here, but, on the contrary, he will be expected to take his place among other mammals, a place which is unlikely to be the first in degree of physical efficiency.

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The second reason for considering the human body on lines similar to those for other species is the similarity of its basic components; individual cells are remarkably alike, as, for instance, ciliated epithelium, the cilia of molluscs, amphibia, and mammals being practically identical.

Goblet cells and multicellular glands in the mucosa again have a common structure and so has olfactory epithelium, whether in an amphibian, a reptile, a bird, or a mammal (Fig. 1).

These preliminary remarks may be superfluous, but the habit of studying structure and function primarily from the human standpoint was adopted some hundreds of years ago and has not been entirely discarded.

Man's Affinities

Man is a member of the order Primates, a term bestowed no doubt because of the inclusion of man, but undeservedly. It seems illogical to describe as the highest order of mammals a collection of defenceless animals, among them galagos and lemurs, monkeys, baboons, and higher apes, since the great majority still retain their arboreal habits, acquired originally to escape predatory enemies and to seek a fresh source of food from the nuts, berries, and leaves of the trees; the immensely powerful and heavy gorilla has partly returned to earth, as well as man, whose intelligent use of weapons make him immune from attack.

Elliot Smith wrote, "The primates at first were a small and humble folk, who led a quiet life, unobtrusive and safe in the branches of trees, taking small part in the fierce competition for size and supremacy

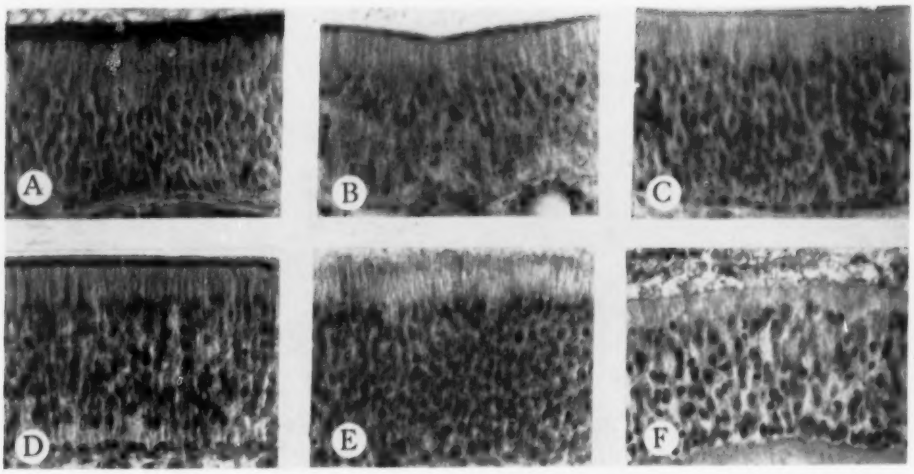


Fig. 1.—Sections of the olfactory epithelium in various animals and man. *A*, slow worm. *B*, pigeon. *C*, guinea pig. *D*, dog. *E*, cat. *F*, man.

There is little difference in thickness or structure. All the sections except that from man are from animals fixed intravitally; this may account for the slightly contracted condition in man.

that was being waged upon the earth beneath them by their carnivorous, ungulate, and other brethren."

However, it must be admitted that primates, culminating in man, have shown the ability to survive and even increase under very varied and difficult conditions; and of course man's mental attainments would certainly justify the name of the order.

The title of first among the order of mammals and in fact of the whole animal kingdom might better be bestowed on the carnivorous cat tribe, the members of which conserve their time and energy by eating herbivores; the bigger cats fear no enemies except man.

Among the anatomical details characteristic of primates are the articulated clavicle, mobile ribs, limbs moving in various directions, five-toed hands and feet, prehensile toes, plantigrade gait, and an extensive dentition. Additional points in which man resembles some other members of the order, such as the structure of the nasal turbinals, the maxillary and ethmoid sinuses, the large epiglottis, the well-formed arytenoepiglottic folds and lateral food channel, and the secondary fixation valve of the larynx, will be referred to as they arise.

Origin of Primates

The adoption of a life in the trees requires consideration as to its origin. It would be possible for limbs to be adapted for climbing from those used for support of the body and for progression, like those of ungulates and most rodents; this would entail difficult anatomical adaptations, but it may have been the means by which there have appeared the semiarboreal chipmunk or the truly arboreal squirrel amongst rodents.

Wood Jones and others have held the opinion that the human stock has never been typically pronograde and four-footed, but thought that the primitive mammal commenced with limbs of little stability but a high degree of motility and a corresponding power of rotation. The water newt is given as an example of an animal of this type, allowing it to clamber by apposition of the feet to the surface to which it clings, a method used by some more primitive human races who do not shin or swarm up a tree like Europeans, but approximate the palms of the hands and the soles of the feet to the trunk and walk or climb up, exactly as a monkey would under similar circumstances.

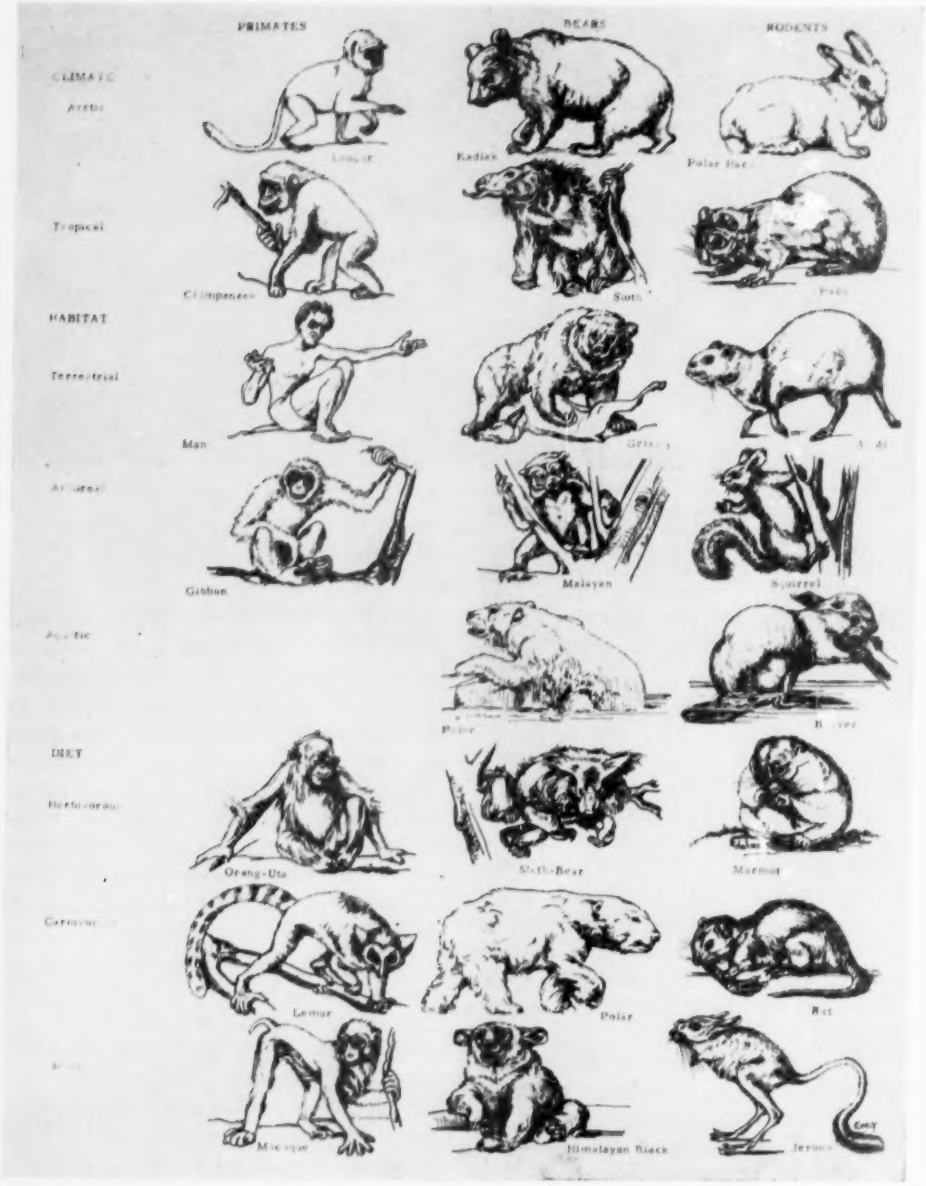


Fig. 2.—Members of three orders are illustrated to indicate the ability of adaptation to various modes of life. In each case certain species are able to live in varying climates and in different habitats; the primates have no aquatic representative; diet again differs between species.

There is only one versative representative, able to adapt himself to any climate or diet, and that is man; his lack of specialization is a strong reason for his ascendancy.

Such races revert to a semiarboreal life by constructing their homes on piles, with entrance up slanting shiny bamboos.

It is not material to the present discussion whether the primates, to which order man belongs, evolved from a terrestrial mammal

or from a reptilian type, since the evidence is all in favor of an arboreal and herbivorous human ancestry; the structure of the human nose, pharynx, and larynx give much information in this respect, and the various details of interest will be discussed.

The existing primates have no relation to other orders, but there is evidence of approximation of some extinct lemurs to inferior orders of mammals, with four premolar teeth.

Chiromys, the aye-aye, somewhat resembles rodents in having a single pair of incisor teeth in each jaw, curved and with sharp chisel-like edges at the extremity designed for gnawing and rasping hard substances. Although these teeth resemble those of rats and beavers and although there is further resemblance in the absence of canine teeth—a gap intervening between the incisors and molars—yet the anatomy of the skeleton and soft parts, and especially the opposable great toe, are those characteristics of a primate; there is only an adaptive resemblance to rodents.

Of primates the habits are varied; the higher apes and monkeys, such as capuchins, are herbivorous, while lemurs and tarsiers are carnivorous; the potto and tree shrew live on insects, and the aye-aye, gibbons, and man have a mixed diet (Fig. 2).

Man is terrestrial, and gorillas are mainly so because of the unsuitability of their bulk to an arboreal existence; baboons usually stay on the ground, although they can climb. Most monkeys, lemurs, chimpanzees, and orangs live in trees, and gibbons show extraordinary agility in swinging from branch to branch.

The structure of the larynx of all primates shows their adaptation for a vegetable diet and their eminent suitability for an arboreal existence; man retains these evidences of his ancestry.

Although examples have been given of species of differing habit, yet on inquiry it is found that most examples are specialized for a particular mode of life; man, however, stands out by reason of his versatility and his ability to live in any part of the world and to subsist on practically all sorts of food.

In this connection of lack of specialization it is interesting to turn to the order of rodents, the members of which show wide variations of mode of life (Fig. 2).

This order of mammals has survived successfully, with a large number of representatives, ranging from the arctic to the equator. Some, such as cavies, are purely herbivorous, while rats are carnivorous; the former are terrestrial; the latter can climb, while squirrels are definitely arboreal; the flying squirrel can glide. Rodents are thus seen to have escaped specialization as an order, unlike so many other mammals. Like primates, they are plantigrade, that is, they walk on the sole of the foot, and some of them, for example, an arboreal mouse, Mus margarettae, have a perfectly opposable thumb and big toe, according to Wood Jones.

Bears have adopted a variety of habits, some living in arctic regions and others on the equator; the Malayan bear is herbivorous and the polar bear is carnivorous; the grizzly is mainly terrestrial; the brown bear can climb, while the Malayan species is semi-arboreal. All walk on the sole of the foot (Fig. 2).

There are obvious specialized characteristics in most orders of mammals, for example, monotremes, edentates, Sirenia, and cetaceans; ungulates have limbs adapted for progression only, with an absence of a clavicle and with fused toes forming hooves. Bats have taken to the air, while insectivores have a specialized diet.

Of carnivores the cat tribe has adopted a flesh diet alone and so has the dog tribe; marine Carnivora show various changes in the limbs suitable for an aquatic existence.

The penalty of specialization is the enslavement of the animal to its environment, with loss of its greatest evolutionary asset of plasticity, as Wood Jones pointed out; this specialization in the end spells the doom of progress. The primate and human stock has not been led astray in this direction. Wood Jones wrote that the human stock never became the slave of its arboreal environment, for it became adapted to tree life

in a strictly tempered manner, and specialized to the successful minimum degree.

Adaptation for a Herbivorous Diet

All animals which live on a vegetable diet masticate their food; to prevent escape from the sides of the mouth cheeks have been evolved, together with a mouth that can be closed. Man is similarly provided.

Purely carnivorous animals have practically no cheeks; they bolt their food after seizing it and tear off pieces of flesh, as, for example, reptiles, birds, and dogs and cats among mammals; in the cat tribe the teeth are adapted solely for seizing prey. With herbivores, closure of the mouth is effected by mobile lips, which were originally evolved for suckling; they are naturally absent in monotremes.

Instead of a larynx which must be closed during swallowing there is, in herbivorous species, a lateral food channel along which liquid or semiliquid nourishment can pass even when the larynx is open, the aperture of the larynx being raised above the floor of the pharynx; this obviates interruption of respiration during the frequent passage of food. This channel is bounded medially by the aryepiglottic fold, which extends from the edge of the epiglottis to the summit of the arytenoid cartilage; when both epiglottis and arytenoid are far apart a strut or prop, the cartilage of Wrisberg, affords support to the otherwise lax fold.

In the human infant the lateral food channel is efficient and can convey milk while respiration continues; but in the adult the aryepiglottic fold is reduced in height in accordance with a mixed diet of firm consistency.

To roof in the lateral food channel there is elongation of lateral palatine folds; their length varies, but in the most elaborate type of food channel they meet posteriorly and form a complete shelf or fold, the arcus palatopharyngeus (Fig. 3).

This fold surrounds the raised aryepiglottic folds of the laryngeal aperture and grips them by virtue of enclosed muscle fibers, thus separating the respiratory and alimentary passages.

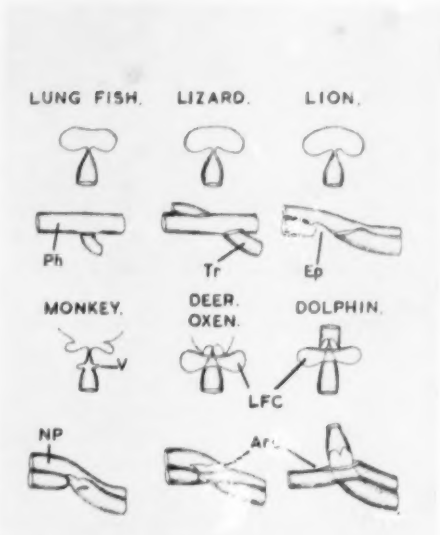


Fig. 3.—Diagram to illustrate the formation of a lateral food channel. Ph=trachea. Ep=epiglottis. NP=nasopharynx. LFC=lateral food channel. Arc=arcus palatopharyngeus. V=ventricle.

In each case the pharynx and larynx are seen in section and in profile. Liquid and food have to pass over the closed larynx in the lung fish, lizard, and lion; the larynx of the latter is of primitive type, with the addition of an epiglottis. The monkey and man have a poor lateral food channel, but in deer and other ungulates and in many rodents it is extremely efficient, and even more so in cetaceans.

The efficiency of construction varies with the diet of the species. In the most efficient type a complete arcus helps to form a very good lateral food channel; examples are marsupials, in which there are false aryepiglottic folds, the majority of rodents and ungulates, Insectivora and most Cetacea.

Those animals which live on grass must eat large quantities to derive sufficient nourishment.

There is no arcus and there are very short lateral palatine folds in most primates, including man, but as an aryepiglottic fold is present, although rather low, the lateral channel is moderately efficient.

There is no arcus, no aryepiglottic folds, and very short lateral palatine folds in civets, genets, cheetahs, and the cat tribe, with consequent absence of a functional lateral food channel; other purely carnivorous animals,

including amphibia, reptiles, and birds, have no lateral channel.

It is interesting to note that certain carnivorous marsupials, the Tasmanian devil and Tasmanial wolf, have a complete arcus, designed for a herbivorous diet but not required for a diet of flesh. The conclusion to be drawn is that marsupials commenced as herbivores and that certain members took to a carnivorous diet.

These deductions, if correct, throw some light on the ancestry of man, pointing to a herbivorous descent; it would agree with other evidence to conclude that his stock started in the trees, living on fruits, nuts, and leaves, with subsequent descent to a terrestrial habitat.

Similar conclusions could apply to some species which are now carnivorous, for instance, members of the dog tribe, bears, raccoons, and weasels. But there is no laryngeal evidence that the cat tribe, with civets, genets, and the cheetah, have any connection with arboreal or herbivorous species.

Although every consideration must be given to the opinion of an authority such as Wood Jones, yet the evidence of the larynx would point to evolution from some terrestrial herbivore, whose larynx has been modified from the primitive reptilian type to one adapted for a diet of herbage; the structure of the nose supports this view.

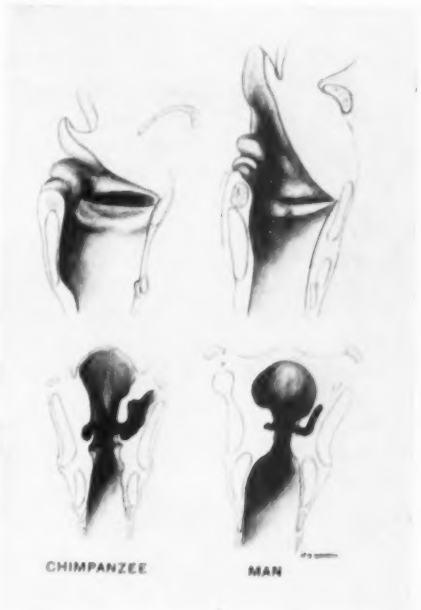
Modifications for Grasping and Climbing

Having decided that the progenitors of man were arboreal and herbivorous, we must now discover what anatomical changes were introduced for a life amongst the trees. The essential requirement was independent use of the forelimbs; there must be the capability of moving the limbs in all directions and not merely backward and forward as in the purely terrestrial ungulates. There must also be adaptation of the fingers of both fore- and hindlimbs for grasping, preferably with the power of opposing the thumb or great toe, or both. When the forelimb is used independently, the pectoral muscles which pull it down must, if possible, have a firm point of origin from the ribs, so that on contraction they shall depress the arm instead of elevating the ribs, as occurs in the forced respiration of asthmatics.

Control by abdominal muscles is reinforced, in my opinion, by closure of the glottis and depression of the diaphragm, whereby intrathoracic pressure is reduced so as to counteract the tendency for expansion of the thorax. The mechanism is one of physiological efficiency, by virtue of pump action on the circulation, with increased output from the left side of the heart.

Most terrestrial herbivorous animals, with their high aryepiglottic folds and flat margins of the glottis, rely solely on sphincteric muscular action for controlling passage of air through the larynx; in all such species which make independent use of the forelimbs there is a fixation valve in the margins of the glottis (Fig. 4).

Fig. 4.—The figure illustrates the powerful valve in the chimpanzee, which prevents entrance of air when closed; the inferior fold in man is shorter and not so upturned, with less efficient valvular action. The larynx of the ape is expanded, with an increased anteroposterior diameter; in man the glottis has a narrower lumen than the trachea. In both specimens the ventricular band is valvular.



The previously flat and undivided thyroarytenoid fold is divided into inferior and superior divisions, with an intervening ventricle. The inferior fold is well adapted for sound production and is therefore generally known in man as the vocal cord or vocal fold; the superior division is the ventricular band, usually down turned and valvular.

This type of larynx is found in animals which use the forelimbs for grasping, even if not for climbing; it appears, therefore, in such rodents as the agouti and marmot. It is well formed in the climbing squirrel and dormouse; the viscacha and guinea pig, which use the limbs for progression only, have no such fixation valve.

All the primates, being of arboreal habit or arboreal ancestry, have such valves, in some instances of extreme efficiency, as in lemurs, which jump long distances from branch to branch; spider monkeys, mangabeys, capuchins, gibbons, and chimpanzees have long sharp inferior folds, in accordance with their active arboreal habits, but gorillas are slightly less well equipped.

Man has an efficient inlet valve because of his ability to use the arms freely for many purposes; his abandonment of an arboreal existence allows him to dispense with a very sharp-edged and upturned valve, such as that of lemurs, with some advantage to phonation (Fig. 4).

It has already been observed that man has escaped overspecialization; this is made clear from a study of his use of the forelimbs and hands.

To refer again to Wood Jones, it is to be noted that the more thoroughly an animal becomes arboreal, the more perfect becomes its hand grasp; from grasping branches the animal learns to grasp food and to convey it to its mouth with its hand. It was the differentiation into two hands and two feet that provided the great strength of the stock from which man arose; anthropoids as a rule have the thumb and big toe opposable and well developed.

In respect of use of the paws or hands, it is interesting to note that the tree shrew, a small animal classed among the primates and a possible originator of the human stock, is not only adept in climbing and jumping about in trees, but also has the power of grasping food and of raising it to the mouth. This animal lives on insects and has not become independent of the jaws for seizing food, since its snout is long and prominent; the change which hand feeding produces is recession of the snout region, but this change has not yet occurred in this instance.

Wood Jones pointed out the effect which independent use of the paws or hands for grasping had on the snout; the latter is prominent in four-footed animals which crop herbage or seize prey while supported on their legs, as, for instance, ungulates, most terrestrial rodents, and the dog and weasel tribes amongst Carnivora (Fig. 5).

But when the ability to grasp food with the forelimbs and to carry it to the mouth was acquired, the animal had no need of a long snout; the cat tribe show this ability and many of them are adept at climbing, as, for example, leopards and the smaller cats. Beavers can hold a small object clasped by the palm and claws of one hand, and marmots can pick up their food from the ground.

Of primates the tree shrews and lemurs have a long snout, although they have the power of raising food to the mouth; baboons are similarly long-snouted, but they have mainly abandoned an arboreal existence (Fig. 5).

In the spectral tarsier the snout is reduced, and this allows the eyes to come to the front of the face and to look forward; this prepares the way for stereoscopic vision, the immense importance of which was emphasized by Elliot Smith.

Effects of Arboreal Life on Olfaction

Terrestrial herbivores rely on the sense of smell for the selection of food and for the avoidance of enemies; the olfactory apparatus is not so elaborate as that of Carnivora, which is understandable, since the hunting animal must approach its prey without detection.

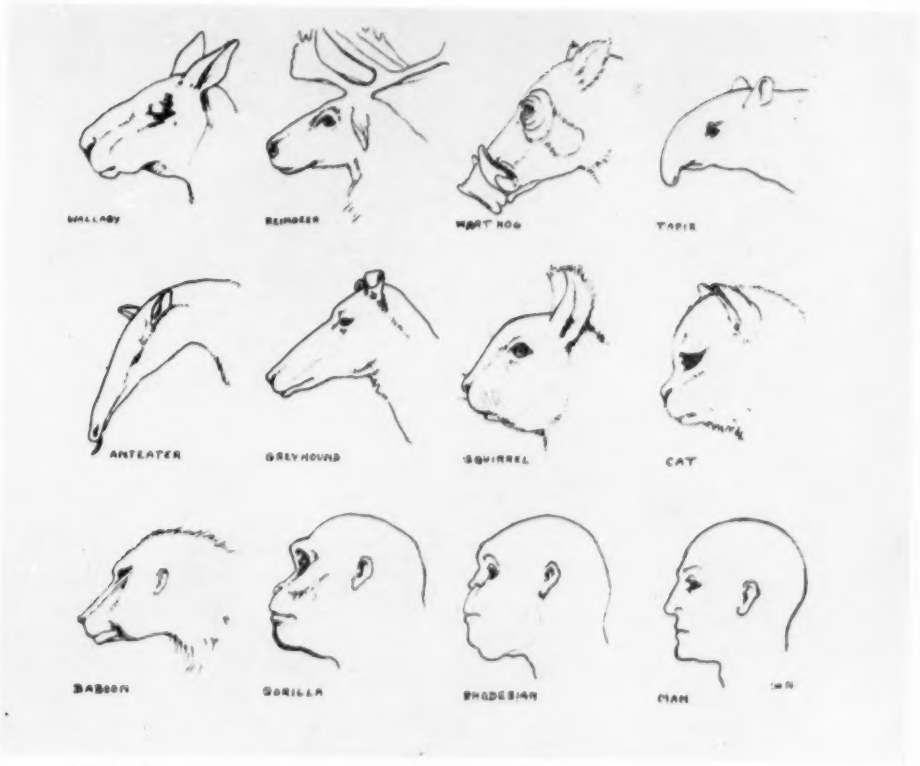


Fig. 5.—Length of the snout in various species. It is long in those that have to reach out for their food, both in Herbivora and in Carnivora, and is short in those where food is brought to the mouth by the forelimbs.

Life among trees is unsuitable for the exercise of the olfactory sense, since odors do not lie as they do on the surface of the earth. Another reason for lack of reliance on olfaction is the elaboration of vision; elevation above the level of the ground increases the range of view and extends the horizon, while the introduction of stereoscopic vision is of considerable advantage.

At the same time the emission of purposive sounds and their perception by the ears allows of intercommunication among the branches, when vision is cut off.

It is found that there is a fairly acute sense of smell in the more lowly primates, such as tree shrews and lemurs, but that as the scale is ascended through monkeys and baboons to the higher apes and man a gradual regression occurs, observable both by anatomical examination and by observation of animal habit (Fig. 6).

The nose of the tree shrew has well-developed ethmoturbinal bodies to carry olfactory epithelium, similar in structure to such Herbivora as some rodents and ungulates; in accordance with the general rule, there is, in association with this elaborate olfactory system a maxilloturbinal of wide area, in the form of a double scroll, to warm and moisten inspired air (Fig. 9).

To carry many molecules of an olfactory substance and to deposit them on the olfactory mucosa, it is necessary for the absolute humidity of incoming air to be raised so that near saturation shall be reached.

Even though the olfactory and air-conditioning systems of tree shrews and lemurs

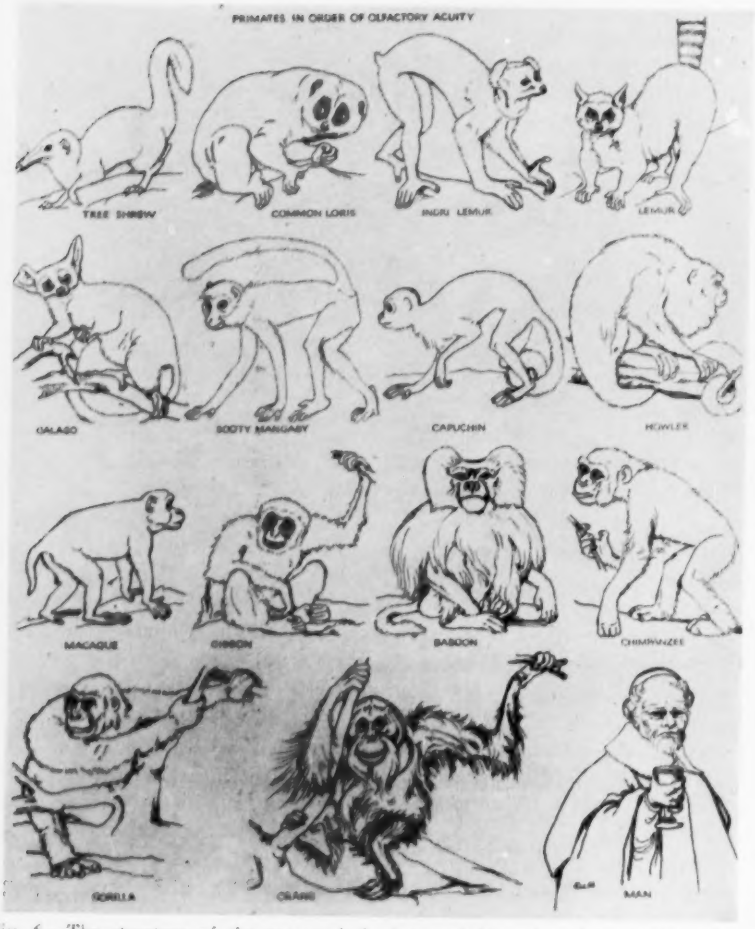


Fig. 6.—The structure of the nose and the known habits of various species point to a diminishing sense of smell through the order of Primates. In the baboon and the higher apes and in man both the ethmoidal turbinal system and the maxilloturbinal are much restricted; the higher apes and man have no ectoturbinals.

There is also a gradual diminution in the size of the olfactory bulb and the cerebral olfactory area from above down.

are very much better developed than those of higher apes and man, yet they bear no comparison to similar systems of keen-scented Carnivora, such as members of the cat and dog tribe, together with genets, civets, badgers, raccoons, weasles, and mongooses. In these animals the maxilloturbinal is greatly increased in area by elaborate branching, while the olfactory mucosa not only occupies all the available space in the nasal fossae, but also extends into frontal and sphenoidal sinuses.

The maxillo- and ethmoturbinals of orangutans and man consist of two single flat plates, the first representing the air-conditioning and the second the olfactory turbinals (Fig. 7).

Man does not rely for his protection on the sense of smell, even though he has returned to a terrestrial existence; his olfactory acuity is feeble, but his discrimination for such odors as the bouquet of wine is good.

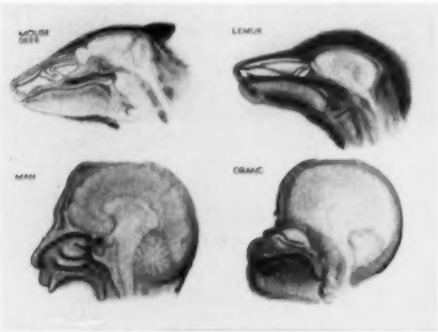


Fig. 7.—Relative olfactory areas. Sagittal sections to show the peripheral olfactory apparatus. The elaborate nose of the lemur resembles that of the deer, both as regards ethmoturbinals and maxilloturbinals.

In man and orang there are only small areas for olfaction and humidification. The size of the olfactory bulb is illustrated.

With these considerations in mind, further thought can be given to the origin of the primates, whether they were evolved from terrestrial mammals, or directly as arboreal species.

Since life in the trees results in reliance on sight and not on olfaction, it is concluded that most monkeys, and more still the higher apes and man, have had a very prolonged arboreal existence; the olfactory area is greatly reduced and the ectoturbinals of higher apes and man are represented by ethmoidal air cells (Fig. 8). In consequence there seems no doubt about the original habitat of the ancestors of the human species.

But if the tree shrews were a progenitor of the anthropoid and human stock, and if they had been evolved primarily as arboreal animals, it would be expected that the olfactory apparatus would show the same regression as in the higher apes; such is not the case, however, since the animals have a well-developed ethmoturbinal area (Fig. 9).

It is reported by Le Gros Clark that the larger species of tree shrews are rather to be regarded as bush animals, inhabiting the lower branches of the trees and the undergrowth of the forest; the smaller species are very active arboreal mammals.

Fig. 8.—Formation of ethmoidal sinuses. Human fetus at 20th week. 1=Ethmoid cell. 2=Tract of maxillary sinus. 3=Ethmoidal sinus. 4=Ectoturbinal. 5=First endoturbinal. 6=Ectoturbinal. 7=Maxilloturbinal.

Two primitive ectoturbinals are to be seen. The upper closes in the cleft between itself and the first endoturbinal, with the formation of an ethmoidal cell or sinus; the ectoturbinal helps to form the medial wall of the ethmoidal bulla. The second or lower ectoturbinal forms the inner wall of a tract which will expand to form the maxillary sinus. Olfactory mucosa is limited to the upper part of the endoturbinal and the corresponding area of the septum.

It would appear, on this reasoning, that some small animal of this type, not permanently arboreal, gave rise to the anthropoid and human stock, and that these adopted a purely arboreal existence, with the acquirement of the characteristics known to follow this type of life.

Comparison can again be made with various species of rodents, some terrestrial, some facultative climbers like the chipmunk, and others, the squirrels, truly arboreal.

The connection between the use of the olfactory sense and the structure of the brain must be considered (Fig. 10).

Fig. 9.—Sagittal section of head of tree shrew (Tupaia). There is a long nasoturbinal body and four well-formed endoturbinals, the last of which projects into a sphenoid recess. The maxilloturbinal is partly hidden by the first endoturbinal but is large and in the form of a double scroll.

The nose resembles that of lemurs and appears to provide for considerable power of olfaction; this no doubt of great value to an insectivorous animal.

Elliot Smith studied the question in great detail, and his writings explain the changes entailed.

"The adoption by some of the shrews of the habit of living in trees brought about profound changes in the relative proportions of the brain. The sense of vision became enhanced in importance, and the sense of smell correspondingly reduced; but, in addition, the senses of touch and hearing, and the power of agility of movement, were considerably enhanced. In one of these groups the importance of vision became still further increased, and the result of this was to bring into existence the Order Primates."

In primitive mammals smell is the chief guide of the animal, and this applies to lemurs; but in the spectral tarsier and its group vision replaces the olfactory sense in importance. In the forerunners of the Mammalia the cerebral hemisphere was predominantly olfactory in function, as Elliot Smith pointed out.

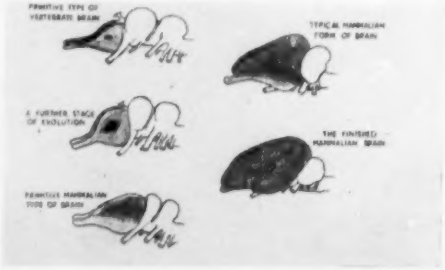
"To a small land grubbing animal the guidance of smell impressions, whether in search for food or as a means of recognition of friends or enemies, sexual mates or rivals, was much more serviceable than all the other senses.

"Once such a creature left the ground and took to an arboreal life all this was changed; for the guidance of the olfactory sense lost much of its usefulness.

"In the struggle for existence, therefore, all arboreal mammals, such as the Tree Shrews, suffer a marked diminution of their olfactory apparatus and develop a considerable neopallium, in which relatively large areas are given up to visual, tactile, acoustic, kinaesthetic, and motor functions, as well as to the purpose of providing a mechanism for mutually blending in consciousness the effects of the impressions pouring in through the avenues of the different senses."

Fig. 10.—Relative size of olfactory area. Diagram to illustrate the areas of the cerebral hemisphere devoted to olfactory (wash) and non-olfactory impressions (stippled).

The illustrations show, in each case, the forebrain, the midbrain, and the hindbrain, and illustrate the increase of the former in higher species. The diminishing size of the olfactory bulb and olfactory tract, together with the reduced area of the cerebrum devoted to olfactory sensation, are outlined. (From Wood Jones: "Arboreal Man.")



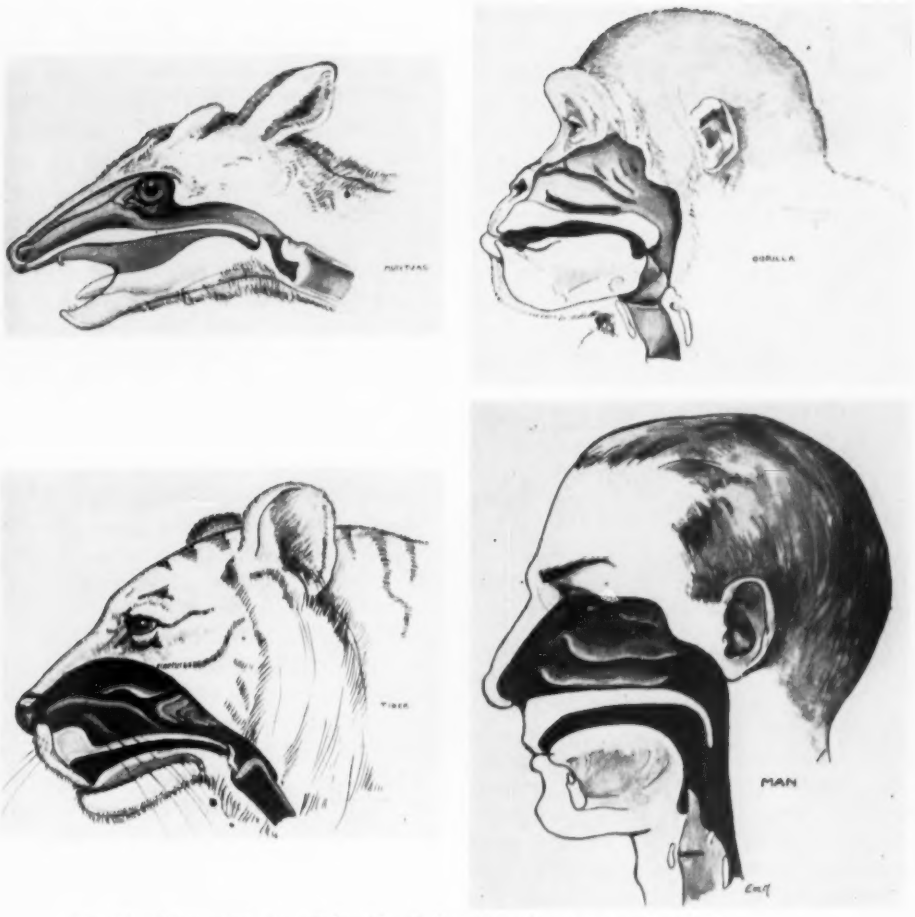


Fig. 11.—Illustrating the relationship of the epiglottis and the soft palate.
In the keen-scented herbivorous muntjac (Cervulus muntjac) and the carnivorous tiger (Panthera tigris) the epiglottis lies above the velum, preventing buccal respiration. The microsmatic gorilla has an epiglottis separated by a small gap from the palate, while in man there is a wide gap; the low position of the larynx and the curving of the tongue are shown in the last figure.

The brain of the tree shrew, Tupaia, shows a reduction of the olfactory area as compared with that of the jumping shrew, Macroscelides, but it is considerably more extensive than that of the tarsier, an animal in which vision has entirely usurped the controlling place once occupied by smell; these observations fit in with the structure of the nasal organ.

Another evidence of adaptation for keenness of the sense of smell is the epiglottis, a flap designed to prevent air entering through the mouth when it is open for eating grass or other food; mouth breathing would divert odorous air from the olfactory area (Fig. 11).

Tree shrews, lorises, and lemurs have a big epiglottis, but it is slightly less well formed in monkeys and baboons and is of reduced size in the higher apes and man.

To complete the continuity of nasal and laryngeal airways there is extension of the velum of the soft palate; the epiglottis lies

above it, with a hyoepiglottic muscle to withdraw it on necessity.

In the orang, chimpanzee, and gorilla the palate is rather short, only just coming into contact with the epiglottis; in man a wide gap intervenes (Fig. 11).

Not only is reduction of the olfactory sense a reason for separation of the palate and epiglottis, but a marked influence is exerted by descent of the larynx in the neck. The man-like apes adopt a slouching attitude for progression, using their forelimbs as props; the snout projects, and the tongue lies flat in the mouth. Changes in the vertebro-occipital and pituitary angles, due to partial flexion of the head on the vertebral column, lead to descent of the larynx in the neck, but to a slight degree only in the apes. In man recession of the jaws has led to backward displacement of the tongue, the posterior part being recurved so as to lie in the pharnyx; the larynx must, of necessity, change position in a downward direction (Fig. 13).

A word must be said, in connection with olfaction, about the paranasal sinuses. In man the presence of ethmoidal cells represents a closing in of unwanted ethmoturbinals, originally designed to carry olfactory mucous membrane, and this gives evidence of an ancestry with keener powers of scent (Fig. 8). The maxillary sinus is a hollow and unwanted air space left in the upper jaw as the result of medial migration of flat turbinals which must, of necessity, lie near the nasal septum.

The sphenoidal and frontal sinuses of apes and man are difficult to explain; they are evolved in macrosmatic Carnivora to house extensions of olfactory ethmoturbinals. Man and some primates have no macrosmatic carnivorous ancestors and yet they retain hollow sphenoidal and frontal sinuses in a few instances; the reason is not apparent, but the various possibilities cannot be considered here.

In connection with a review of the olfactory apparatus the question of air conditioning arises. Warming and moistening are carried out mainly by the maxilloturbinal body in the nose. This, although flat and of small area in man, is still sufficient for the needs of his respiratory system, supplemented by the giving off of additional warmth and moisture in the trachea, bronchi, and bronchioles.

In regard to the small area sufficient for air conditioning in apes and man, the conclusion is reached that the elaborately furrowed or branched maxilloturbinal body, with a very wide area, is a characteristic of macrosmatic species and is developed for olfactory purposes. The knowledge that olfaction in tree shrews and lemurs is better than in higher species enables the reason for their double-scrolled maxilloturbinal, of considerable area, to be understood (Fig. 7).

Another change of some interest is the great extent of ciliated epithelium in the nose of man; almost all of the ethmoturbinals and maxilloturbinal and also the nasal septum are ciliated, unlike those of many keen-scented species, whose enormous olfactory area has no cilia, with an absence also in many instances on part of the septum and on the maxilloturbinal.

The ciliary streams in man are orderly and easily followed, but in spite of this protection, afforded by the regression of his olfactory sense, he is very prone to nasal infections, mainly because of his facultative mouth breathing.

The main advantage to man of these various adaptations is the power of emitting sounds freely through the mouth and the faculty thus afforded of developing elaborate powers of speech.

Changes in Respiration

Four-footed terrestrial animals, such as antelopes, deer, and hares, frequently depend for their survival on speed; their respiratory apparatus must be efficient, and the upper respiratory airway must allow free passage of air.

To attain this end the larynx must be of adequate size, with wide opening of the glottis by means of long arytenoid carti-

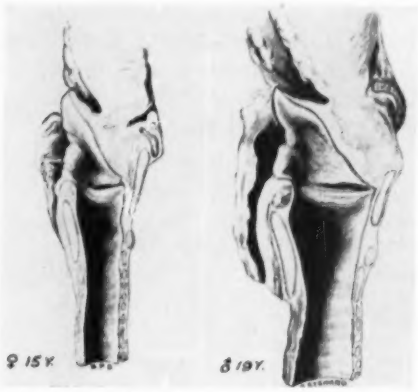


Fig. 12.—Section of larynx of human male and female. The narrow glottis of the female contrasts with the funnel-shaped and expanded larynx of the male after puberty; there is considerable increase in the anteroposterior diameter, with longer vocal folds.

lages; the optimum length is 7/10 of the anteroposterior diameter of the glottis.

Although there is the necessity of violent exercise in trees by such active animals as gibbons, yet with the more leisurely higher apes movement is slower; chimpanzees are active, adult gorillas rather less so, while orangutans are sluggish.

Inlet of air is free in species with a big larynx and long arytenoid cartilages; dogs are of this type but none of the primates, the cartilages in the latter being short in all instances. The long anteroposterior diameter of the larynx compensates for this deficiency in practically all lemurs, monkeys, baboons, and the higher apes; the larynx is particularly large in the agile lemurs and spider monkeys. The larynx of man is small in comparison, and the arytenoids are very short, particularly in women; the fetus and infant show an interesting expansion of the larynx, with backward tilting of the posterior plate of the cricoid cartilage. There is marked extension of the length of the glottis in the male at puberty (Fig. 12).

Man is unable to run so fast as such terrestrial species as kangaroos, deer and antelopes, or wolves, nor can he climb with the agility of monkeys; he does not rely for his survival on muscular powers, but rather on his superior intelligence and the advantages it affords him.

Man is at a respiratory disadvantage because of the tortuosity of his upper airway, with angles in the nasal fossae, in the nasopharynx, and at the larynx; the airway of fast-running animals is almost straight.

The power of expulsion of dead space air is poor in man as compared with an animal such as a horse, which has a broad sheet of muscle stretching across the trachea posteriorly; there are movements of the trachea and bronchi, more noticeable in children, but not of wide extent, except in such embarrassed individuals as asthmatics.

As regards rebreathing of air, a feature of many primates, there is no provision in the human anatomy for this, the saccule being small and functionless.

The efficiency of respiration in man's arboreal ancestors must have been greatly superior to that of modern man; such early types as Rhodesian man no doubt had capacious lungs, a long larynx, and lengthy arytenoid cartilages, with a somewhat less tortuous airway.

Evolution of Speech

Life among trees calls for the use of sound as a means of keeping touch between animals, especially those of a roving and active habit. It is noticeable that perching birds are noisy as a class, while species inhabiting open spaces or mountains, such as eagles, are silent.

Sound is also used as a method of warning when animals are threatened by predatory enemies such as leopards. Production of sound for the emission of simple cries was elaborated by the growing intelligence of early man into a wide code of language.

There are three components of the mammalian vocal system, the lungs taking the place of bellows, the larynx acting as a vibrating reed, and the thorax, pharynx, mouth, and nasal passages providing resonators. All these organs are present for purposes of respiration and forelimb fixa-

tion, and no modifications are necessary for their use for vocal purposes.

With birds the position is different, the great length of the arytenoid cartilages being unsuitable for vibration and sound production, thereby necessitating the production of an entirely separate and specialized vocal apparatus, the syrinx.

The presence of short arytenoid cartilages and long membranous thyroarytenoid folds, with free and well-defined margins, supported by thyroarytenoid muscles of variable elasticity, allows man to produce sounds of wide range and pleasing quality; the latter attribute depends on the edges of the vocal folds, which in the human body are rounded, unlike the sharp-edged folds in such animals as lemurs and gibbons, whose high overtones are shrill and piercing (Fig. 4).

Almost any mammalian larynx can produce mixed sounds of variable pitch, but not always with the range and degree of control peculiar to man; what is of greater importance is the mechanism for amplification and determination of quality, dependent on the resonators.

In man descent of the larynx in the neck has caused the pharynx to be roomy, and separation of the epiglottis from the soft palate allows laryngeal sounds to escape either through the nose or mouth, or both; the nasopharynx is fairly capacious, and the nasal fossae, although not wide, are not crowded with turbinals as in keen-scented animals (Fig. 11).

The resonators are therefore superior to those of other mammals for the production of vowels and consonants, allowing a wide register to be available for song and an elaborate vocabulary for speech.

Later Modifications for Terrestrial Life

Having been enabled by superior intelligence to leave the shelter of the trees, the ancestors of man further developed the code of signals derived from primitive instinctive calls and cries. Although man was not perpetually hidden in dense forests and although he possessed efficient sight, yet the conveyance of ideas by speech was naturally of great importance and to be retained; this advance followed the gain in intelligence, but at the same time it gave a further impetus to intellectual progress.

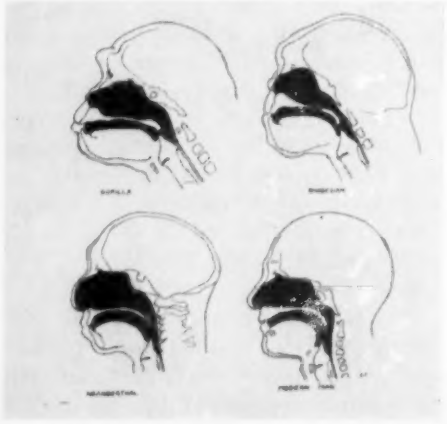
Certain changes occurred in the vocal apparatus. The lungs remained adequate for use as bellows. The vibrating vocal folds became less sharp-edged, having less strain thrown on them for climbing, although still being of great value for forelimb efforts; consequently the higher overtones were of less intensity, with a mellower quality of the voice.

The ear-piercing screams of gibbons demonstrate the effect of inferior thyroarytenoid folds with free, sharp-edged margins.

The pharynx became larger as man took to soft cooked food; his jaws receded and came to be under the cranial cavity, which itself grew forward to house the enlarged brain. The larynx descended in the neck and came to lie opposite cervical vertebrae and not against the base of the skull (Fig. 13).

As the grinding surface of the somewhat crowded teeth was reduced, and also the

Fig. 13.—Position of the larynx. The recessive jaws of modern man are in contrast with the prognathous jaw of earlier human types and higher apes. The tongue is curved and part is pharyngeal, causing the larynx to descend in the neck. The face of modern man lies beneath the cranial cavity, instead of projecting in front.



size of the tongue and palate diminished, so the mouth became smaller as the pharynx enlarged.

There was, however, still present an efficient apparatus for the production of speech and song, with stops for consonants provided by a free soft palate and by mobile lips and tongue.

More primitive types of man, such as the Rhodesian, must have had a bigger chest, of greater lung capacity, than that of modern man, a larger larynx with longer arytenoid cartilages and sharper inferior thyroarytenoid folds, a smaller pharynx, an epiglottis near to but separated from the soft palate, a much bigger mouth, with a flatter tongue, and nasal fossae of large capacity. His voice was no doubt powerful and deep but of harsh quality (Fig. 13).

The nose of gorillas and orangs is shorter than the snout, and that of Rhodesian man must have been similar; modern man's nose projects beyond the jaws, and the downward direction of the nostrils causes inspired air to pass over intended food and to give information as to its nature. Alone among primates in having a long nose is the proboscis monkey, whose nasal organ has been considered to act as an adornment.

Conclusion

The various changes in human anatomy, evolved in response to varying modes of life, have resulted in a structure of extreme versatility. There is no particular specialization such as has prevented further progress in many animals. Man can live in any climate, can eat all sorts of food, and can converse with ease; his intellectual advancement has enabled him to control other species, not by bodily strength, but by the use of extraneous accessories.

Some authorities, however, are somewhat gloomy as to man's future. Wood Jones, in "Trends of Life," writes about the evolutionary progress of mankind: "He has now made his own environment of what is known as civilisation, which is an extremely complex one; but in doing it, he has become its slave: moreover, his slavery is the degenerative bondage of the dependent domesticated animal." "With his wants provided by artificial conditions of civilisation, it may be that his natural intelligence is diminishing."

When one observes the reliance of the present age on newspapers, the wireless and television, on the cinema and gramophones, it is obvious that constructive thought is absent in the majority of the population, who prefer to live the life of robots.

The everyday dissipation of radiations from luminous watches, television sets, and x-ray tubes offers a potential danger, of more import than the problematical hazards of atomic warfare.

The medical profession is in the position to point out these dangers, if it considers the human race to be worthy of survival.

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The Function of the Paranasal Sinuses

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Numerous opinions have been expressed on the question of the function of the paranasal sinuses but without any general agreement. One reason for failure to arrive at a positive conclusion has been the mistake of considering the sinuses as a whole; if some separation be made between the various components, the explanation of their purpose is, in many instances, made clear.

I propose to approach the subject from the easiest aspect and to consider first those sinuses which appear to have a positive function; next to consider the sinuses left as unwanted spaces in previously functional areas; and thirdly to review sinuses for which no explanation can be found.

Sinuses of Positive Function

Provision of an Extensive Olfactory Region.—If all vertebrates are reviewed, both as to habit and structure, it will readily be understood that a wide olfactory area is required by the majority, not only for the selection of food or the hunting of prey, but also for recognition of friend or foe and for the locating of individuals of the opposite sex. The structure of the brain gives evidence of the relative reliance on the sense of smell, which in lower vertebrates outweighs all other senses; the area of their cerebral cortex given over to olfactory sensations is predominant, as pointed out by Elliot Smith and Wood Jones; in the higher mammals the distribution is altered, but in many the cerebral olfactory area is still large.

It is found that herbivorous animals have a large olfactory area in the nose, the specialized mucosa covering five or more ethmoturbinal bodies, or endoturbinals, in the medial row, with others, the ectoturbinals, lateral to them; they are thereby enabled to select food under the guidance of the nose and at the same time to gain warning of predatory animals.

But when the Carnivora are examined it is found that the olfactory area is still greater, as might be expected in view of their reliance on the nose for discovering and following intended prey; this is especially noticeable in nocturnal Carnivora such as tigers.

The ethmoturbinals of the Carnivora are arranged in the nasal fossa much as in Herbivora, and in both groups the remaining available space in the nose is occupied by the maxilloturbinal body, which is the main source of moisture for the humidification of inspired air. Water vapor sufficient to saturate the scent-laden air current is essential for the entrapping of olfactory molecules, which are adsorbed by water molecules and then deposited on the olfactory mucosa, probably by the attraction of electrical surface charges.

It is noticeable, when all species of mammals are examined, that the olfactory and air-conditioning areas bear a direct relationship, the latter increasing in complexity and surface area in proportion to the former. The result is that the nasal fossae of keen-scented animals are filled with ethmo- and maxilloturbinates, with little or no free space (Fig. 1).

The Carnivora require a superior olfactory sense to satisfy their appetites, and to attain this end they must have a greater number of olfactory receptors, which means a wider olfactory area. To reach this requirement there is upward expansion of the nasal and frontal bones, which rise above the nasal fossae to house air spaces, pars

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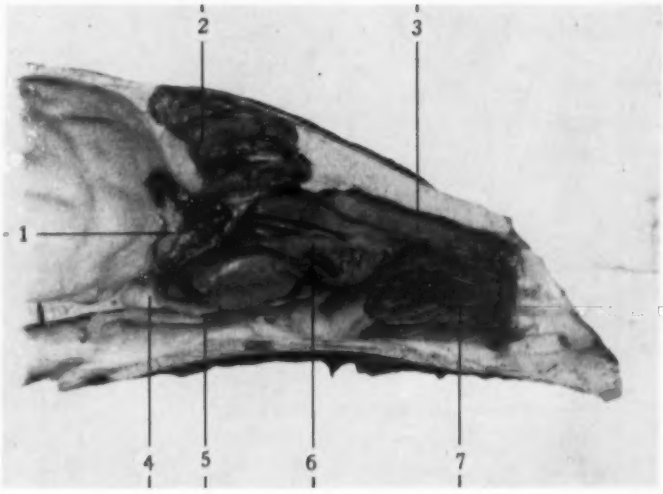
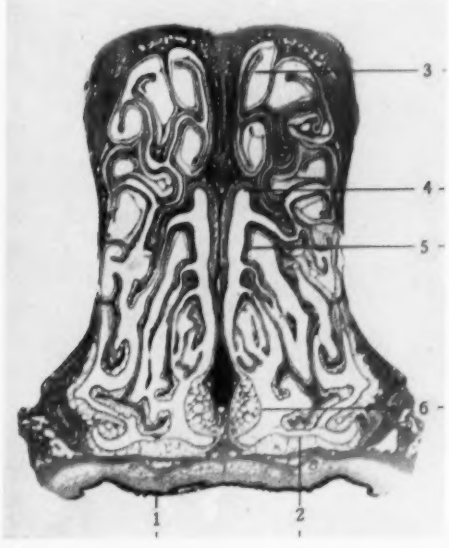


Fig. 1.—Skull of badger (Meles). Sagittal section of the skull to show the extension of olfactory ethmoturbinals into the frontal sinus. 1=Cribriform plate. 2=Ethmoturbinals in frontal sinus. 3=Nasoturbinal. 4=Sphenoid recess. 5=Subethmoidal plate. 6=Endoturbinals. 7=Maxilloturbinal.

nasalis and pars frontalis of the frontal sinus, wherein extensions of the ethmoturbinal system find a place; it must be made clear that this is not merely an excavation of existing bones, but rather the construction of a superimposed upper story (Fig. 2).

Fig. 2.—Coronal section of nose of a cat in the ethmoidal region to show the superimposed frontal sinus, with extension above the level of the nasal fossae of ethmoturbinal bodies. 1=Palate. 2=Ciliated epithelium. 3=Olfactory ethmoturbinals in frontal sinus. 4=Roof of nasal fossa. 5=Olfactory endoturbinal. 6=Swell body.



That these new ethmoturbinal bodies serve the function of olfaction is proved by observing the passage of olfactory nerves into them through an extended cribriform plate and also by histological examination of serial sections.

The exact parallel between the known habits of the Carnivora and the structure of their frontal sinuses, leads to the conclusion that the sense of smell is the reason for the presence of these spaces (Table 1).

In the same category are placed the sphenoidal recesses and sinuses characteristic of Carnivora; here there is backward excavation into the sphenoid bone, with extension into the recess so formed of olfactory ethmoturbinal bodies.

Distribution of Frontal and Sphenoidal Sinuses.—All the members of the dog tribe, including foxes and wolves, together with coatis, raccoons, badgers, the panda, and the kinkajou, have frontal sinuses containing olfactory ethmoturbinals; some have a nasal division and others a frontal component, while certain species have both. The cat tribe, with the exception of the lion, have a similar arrangement; this includes leopards, tigers and other cats, and also hyenas, genets, civets, paradoxures, and mongooses (Table 1).

TABLE 1.—*Distribution of Frontal Sinuses in Mammals*

		Monotremes Marsupials	Edentates	Rodents	Ungulates	Hollow Horned Ungulates	Chiroptera Insectivora	Marine Carnivora	Dogs, Bears, Raccoons, Weasels	Cats, Civets, Hyena	Primates
Nonolfactory		Platypus Echidna Wallaby Thylacine	Pangolin Peba Armadillo	Flying squirrel Ground squirrel	Mouse Deer Chevrotian Roe deer Muntjac	Duiker Impala Nilgai Pronghorn	Shrew Tenrec Hedgehog	Grey seal		Lion	Galogo Slow loris Humboldt's monkey
Absent				Brown rat Australian water rat Water vole Coypu Jerboa Porcupine Paca		Gazelle					Macaque Mangabey Baboon Gibbon Orang Chimpanzee
Absent or very small				Brush-tailed Porcupine Black rat Rabbit Red squirrel		Sheep Oxen Goat	Mole Fruit bat	Common seal	Ferret		Lemur
Pars nasalis only	Small to medium				Syrian hyrax Chital	Ibex	Leaf-nosed bat		Zorilla		
	Small to medium				Hippopotamus						Cercopithecus Man
Pars frontalis only	Large	Tree kangaroo Wombat				Chamois					Man Sifaka Howler monkey
	Very large					Barbary sheep					Gorilla
Pars Nasalis & frontalis	Large				Peccary						
	Very large				Rhinoceros						
Olfactory	Niche	Opossum Bandicoot		Guinea pig	Horse						
Pars nasalis only	Small	Dasyure	Giant ant eater						Fennec fox Otter Weasel	Paradoxure	
	Large	Giant kangaroo									
Pars nasalis & frontalis (olfactory in nasalis only)	Medium									Leopard	
	Large				Tapir Pig				Brown bear	Wild cat Ocelot Lynx Serval	
	Very large		2-Toed sloth 3-Toed sloth						Coati Racoon	Jaguar	

In the first group the ferret has no frontal sinus and the zorilla has an empty one; but the general rule is followed very closely in the vast majority of carnivores.

Of ungulates which live on herbage none have an olfactory frontal sinus, but in some of those which root for their food, the tapir and pig, there is a large cavity containing ethmoidal turbinal bodies. These animals, especially the pigs, are very adept in finding buried food, such as truffles. The closely related peccary and rhinoceros have large empty sinuses, but the horse has only a small niche. It can be concluded, therefore, that of the ungulates those members requiring a particularly keen sense of smell are adequately equipped.

Of the rodents none have an olfactory frontal sinus; and the same observation applies to bats, insectivores, and marine Carnivora, that is, the seals, sea lions, and walrus (Table 1).

Monotremes have no frontal sinuses, but amongst marsupials the koala has a large cavity containing extensions of ethmoturbinals; since it lives in trees its olfactory requirements might be expected to be slight.

The distribution of sphenoidal sinuses containing olfactory mucosa follows much the same lines, the cavity obviously serving the sense of smell in the Carnivora and being absent or very small and nonolfactory in rodents; the rooting ungulates have an olfactory sphenoidal recess, and so have sheep, goats, and oxen, but in the latter the cavity is insignificant.

An order still to be considered is that of the Primates. The majority have no frontal or sphenoidal sinuses, and in only one example, the tree shrew, is there an extension of olfactory mucosa into sphenoid recess; this small insectivorous animal has a large ethmoturbinal system and apparently a good sense of smell.

In sifakas, howler monkeys, gorillas, and man the frontal sinus is large but empty, and the same applies to the sphenoid, where these representatives are joined by the chimpanzee and orang (Fig. 3).

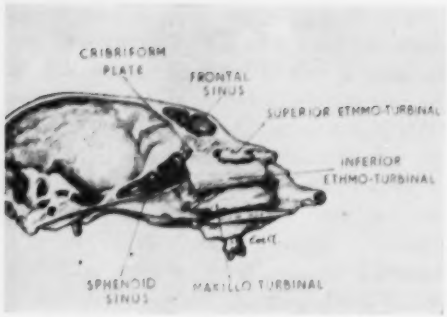


Fig. 3.—Sagittal section of skull of Mycetes, a howler monkey, to show the frontal and spenoidal sinuses.

It is impossible to explain why these sinuses, poorly represented in the humblest primate, the tree shrew, should appear in the higher members, whose olfactory area is very restricted and whose sense of smell is feeble.

In man there does not appear to be any functional reason for the appearance of air spaces, and the irregularity of their distribution, often with complete absence, suggests that they are only unwanted residual spaces; this, however, is not a very satisfactory explanation.

Unwanted Air Spaces

Air Sinuses Resulting from Retrogressive Processes.—Those sinuses having been considered to which a purposive function can be ascribed in the great majority of their possessors, it is now desirable to turn to cavities left as unwanted spaces as a result of diminution of the olfactory area or of the associated and parallel air-conditioning system.

Ethmoidal Air Cells.—It has already been mentioned that many keen-scented animals have more than one row of ethmoturbinals, covered with olfactory mucosa (Fig. 4, right). The higher apes and man have no

Fig. 4.—Formation of ethmoidal sinuses from inclusion of unwanted ectoturbinal bodies. Left, human fetus, 20 weeks: 1=Ethmoidal cell. 2=Developing maxillary sinus. 3=Ethmoidal cell. 4=Ectoturbinal. 5=Endoturbinal. 6=Ectoturbinal. 7=Maxilloturbinal. Right, rabbit: 1=Ectoturbinal. 2=Endoturbinal. 3=Maxillary sinus. 4=Nasopharynx.
In the rabbit unwanted space leads to formation of maxillary sinuses.

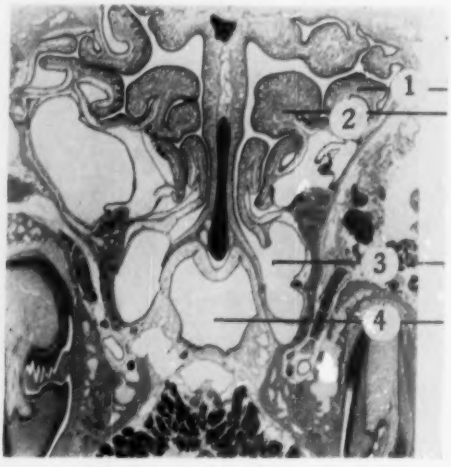


TABLE 2.—*The Relative Area of the Maxilloturbinal Body*

	Monotremes Marsupials	Edentates	Rodents	Ungulates	Hollow Horned Ungulates	Chiroptera Insectivora	Marine Carnivora	Dogs, Bears, Raccoons, Weasels	Cats, Civets, Hyenas	Primates
Single Scroll										
Short	Koala									Sifaka Orang Chimpanzee Gorilla Man
Medium						Fruit bat Vampire bat				
Long				White Lipped peccary		Leaf-nosed bat				Lemur
Very long		Great ant eater								Baboon
Double Scroll										
Short		Sloth	Dormouse Guinea pig							Loris Capuchin Gibbon Howler monkey
Medium				Syrian hyrax					Jaguar Hyena Lion Leopard Caracal	
Long			Water rat Coypu Paca Agouti Brown rat	Hippopotamus Wild boar Pig Collared peccary	Chamois Ox Sheep Muntjac Mouse deer Roe deer Antelopes Pronghorn					
Very long	Echidna Bandicoot					Mole				
Grooved or Folded										
Short			Marmot Red squirrel Flying squirrel							
Medium										
Long	Wallaby Opossum Platypus								Binturong	
Branching										
Short									Cat Ocelot	
Medium	Tasmanian wolf		Rabbit				Seal	Panda Kinkajou Badger Otter		
Long	Dasyure					Hedgehog Tenrec		Ferret Racoon Coati Weasel Bears Dogs Foxes Mongoose	Civet Genet	

The area of the maxilloturbinal body is least in those with a short nose and a single scroll, and greatest in those with a long snout and a branching maxilloturbinal; the microsmatic Primates are in the former group and the macrosmatic Carnivora in the latter. Rodents and ungulates are intermediate. The area of maxilloturbinal appears to bear a direct relation to the acuity of olfaction.

longer any need of a wide olfactory area, and the projections corresponding to ectoturbinals carry no olfactory mucous membrane. Some of these projections, separated by deep clefts, fuse with one another, thus enclosing small air spaces at their outer extremities; these spaces represent the ethmoidal air sinuses, communicating with the nasal fossae by narrow ostia. They are found only in the higher apes and man. In man the developmental changes can be seen in sections of a fetus, where thick ectoturbinals enclose part of the intervening space; the ectoturbinals eventually become thin and help to form the ethmoidal bulla (Fig. 4, left).

Relation of the Maxilloturbinal Body to the Snout.—To understand the formation of maxillary sinuses it is necessary to examine the structure of the upper jaw and the air-conditioning system contained in it. The maxillae serve to carry the teeth and palate, essential for the seizing and preliminary preparation of food; for this purpose they must be of adequate size, especially in carnivorous animals which catch prey with their teeth, and in ungulates and rodents which crop herbage. Many animals capable of killing food with the forelimbs, for instance, cats, convey food to the mouth with the paws and do not need a projecting snout, as pointed out by Wood Jones.

The size and disposition of the maxilloturbinal bodies already referred to as best developed in keen-scented animals, have an influence on the design of the upper jaw (Table 2).

It is found that maxilloturbinals of very extensive surface area are present in most of the Carnivora. These animals have already been referred to as provided with a wide olfactory area, extending into frontal or sphenoidal sinuses; the function of air conditioning by them is complementary to that of olfaction.

In the majority of these species a wide air-conditioning area is provided by branching of the maxilloturbinal, the reduplication so attained serving the desired purpose; the highest degree of branching is found in dogs, foxes, bears, badgers, otters, weasels, raccoons, ferrets, coatis, mongooses, tigers, civets, and genets. Slightly smaller maxilloturbinals are present in the panda, kinkajou, ocelot, and some cats. It will be observed that a very close parallel exists between olfactory frontal and sphenoid sinuses and elaborate maxilloturbinals (Fig. 1).

A branching maxilloturbinal is present in two predatory carnivorous marsupials, the Tasmanian wolf and the dasyure. Similar are two keen-scented Insectivora, the hedgehog and the tenrec.

Another method of providing a wide area is by infolding of the turbinal, as seen in the binturong.

A less elaborate maxilloturbinal is one taking the form of a double scroll; the area is proportional to the length of the snout. This type is present in most rodents, except the marmot and the squirrel, where the maxilloturbinal is folded, and in the rabbit, where it is branching. A double scroll is seen in the jaguar and lion, leopard, hyena, and caracal. Of ungulates, the hippopotamus, pigs, and peccaries, chamois, oxen, sheep, deer, and antelopes have a double scroll.

Primates, with their feeble powers of scent, have short snouts, and a small maxilloturbinal. There is a double scroll in howler and capuchin monkeys, in lorises and gibbons; baboons, the higher apes, and man, all microsmatic, have a single scroll (Figs. 3 and 4).

The Maxillary Sinus

The practical deductions as regards the maxillary sinuses are that in animals with a large and branching maxilloturbinal there is little or no space left unfilled in the maxilla; there are no lateral recesses (Fig. 5, right). When a scrolled maxilloturbinal is present, the area occupied is less than with a branching structure. It is essential that inspired air should come into contact with the mucosal surfaces, and consequently little space is left between the septum and

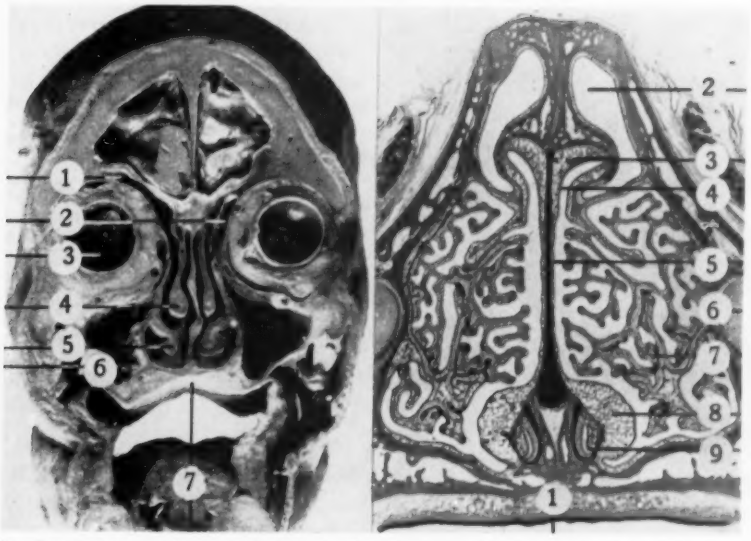


Fig. 5.—Coronal section of the head of a human subject, on the left, and of a cat (Felis domestica), on the right. Left: 1=Frontal sinus. 2=Ethmoidal cell. 3=Orbit. 4=Ethmoturbinal. 5=Maxilloturbinal. 6=Maxillary sinus. 7=Palate. Right: 1=Palate. 2=Frontal sinus. 3=Vascular spaces. 4=Olfactory mucosa. 5=Ciliated epithelium. 6=Tooth. 7=Maxilloturbinal. 8=Swell body. 9=Organ of Jacobson.

The section is intended to show that, with diminution in the size of the maxilloturbinal, a space remains unoccupied laterally, forming a maxillary sinus. This is big in the human and absent in the cat, which has a branching maxilloturbinal.

the maxilloturbinal. To attain this proximity the scrolled maxilloturbinal is situated near the middle line, its attachment to the lateral wall shifting inwards to a corresponding degree (Fig. 5, left). In some cases, notably in baboons, the whole lateral wall of the maxilla carrying the maxilloturbinal is displaced inwards, causing the cheek to be depressed and sunken (Fig. 6).

Fig. 6.—Head of a baboon (Cynocephalus). The drawing illustrates the sinking in of the cheek, with absence of a maxillary sinus.

In others, for instance, the higher apes and man, the maxilla curves outwards to form a prominent cheek, a fresh plate of bone developing to support the maxilloturbinal. Consequently an unfilled space is left lateral to this bony plate, constituting a maxillary recess, or sinus, according to the degree of closure; its point of communication is between ectoturbinal bodies or their relics (Fig. 5, left). Alteration in the shape of the maxilla would give man sunken cheeks, as in baboons, with absence of a maxillary sinus (Fig. 7). The greater part of the recess may be open to the nasal fossa, but in many instances it is shut off by the party wall; in the koala, for instance, the communication is wide, but in man it is restricted and appears only as a narrow ostium.

The long-snouted ungulates show this inward movement of double-scrolled maxilloturbinals; some of them have not only a lateral recess, but also a cavity beneath the nasal fossae, between the latter and the

Fig. 7.—Appearance of a man with no maxillary sinuses, as in the baboon.

palate, in order to restrict and direct the air currents.

Not only may a recess be left lateral to the maxilloturbinal, but if the ethmoturbinals do not completely fill the posterior half of the nose, there may be an air space there also (Fig. 4, right). As with air currents in the air-conditioning region of the nose, where contact with the mucous membrane is desirable, so in the olfactory area the air passages are restricted, in order that air laden with olfactory molecules may impinge and deposit particles on the mucosa. Consequently, no maxillary recesses are present in the animals of keenest olfactory sense, but they are found in many species of less acute olfactory powers where there is a disproportion between the ethmoturbinals and the breadth of the nasal fossae; the distance between the orbits has an influence (Table 3).

Large maxillary recesses or sinuses are present in man and the higher apes, in capuchin and howler monkeys; they are small in Cercopithecus monkeys and absent in baboons, lorises, and galagos.

Maxillary sinuses are present in deer and various other ungulates, in many rodents, and a few marsupials; the koala has a large recess, almost completely open. There are no maxillary sinuses in monotremes, wallabies, and kangaroos.

Maxillary sinuses are absent in most Carnivora, including many of the cat tribe, most dogs and bears; in some a recess accommodates the maxilloturbinal body, particularly in coatis, raccoons, ferrets, martens, and panda. Certain Carnivora have a small posterior recess lateral to the ethmoturbinal system, but none in the region of the maxilloturbinal.

The ratio between the space occupied by ethmoidal and maxillary turbinals depends not only on the breadth of the snout, but also on its length, as exemplified by the long-snouted ungulates; the length of the nose does not always correspond to that of the snout, and this has an influence on the formation of maxillary sinuses. Although the higher apes, and particularly man, have short nasal fossae, they possess shrunken turbinals, and consequently have large maxillary air spaces (Tables 2 and 3).

Cranial Air Spaces of Unexplained Function

Hollow-Horned Ungulates.—The presence of extensive air spaces in the skulls of ungulates is sometimes advanced as an argument against the validity of the explanation put forward in regard to the frontal sinuses of Carnivora; I consider this to be an error and feel that the present problem must be examined independently.

The hollow-horned ungulates, such as oxen, goats, sheep, and also elephants and giraffes, have air spaces extending over the greater part of the cranial vault, communicating with the nose in the frontal region and extending into the horns; the cavities do not contain olfactory mucosa, although their point of derivation is the nose.

A reason for this excavation sometimes given is distribution of the stress of the horns all over the cranium, with possible avoidance of concussion of the brain.

TABLE 3.—*Relative Size of Maxillary Sinus*

	Monotremes Marsupials	Edentates	Rodents	Ungulates	Chiroptera Insectivora	Seals, Dogs Bears, Raccoons, Weasels	Cats, Civets, Hyenas	Primates
Absent or open recess for maxilloturbinal	Echidna Ornithorynchus Wallaby Kangaroo	Sloth	Water vole	Tapir	Fruit bats Shrew Mole	Seal Tayra Badger Otter Kinkajou Bears Jackal Cape hunting dog Domestic dogs Foxes	Hyena Palm civets Genet Mongoose Lion Leopard Jaguar Serval Ocelot Wild cat Domestic cat Caracal Lynx	Galago Loris Baboon
Small recess	Opossum Dasyure	Armadillo	Agouti Coypu Dormouse		Hedgehog	Coati Racoon Ferret Polecat Pine marten Panda		Lemur
Small sinus		Great ant eater	Hare Squirrel Guinea pig Rat Rabbit	Hyrax Peccary				Cercopithecus monkey
Big sinus	Bandicoot Koala			Horse Pig Deer Chamois Goat Ox	Vampire bat			Sifaka Capuchin monkey Howler monkey Gibbon Orang Chimpanzee Gorilla Man

The table shows that the Carnivora, with extensive olfactory and air-conditioning systems, have no maxillary sinuses, since there is no space in the snout. The Primates, with a poor olfactory sense, have restricted areas and maxillary sinuses occupying unwanted space.

But when other horned ungulates are examined, such as the moose or elk, the wapiti and red deer, it is found that the horns, often of enormous size, are attached directly to the cranial vault, with no intervening air spaces. These animals make much use of their horns for defense and attack and manage to bear the weight and to endure the shock of impact without obvious damage. Since the elephant has no horns, but tusks growing out of the maxillae, it again would derive no benefit from its air spaces in combat.

I have no explanation to advance for this apparently illogical distribution of air spaces, but repeat that the problem would seem to be best considered independently.

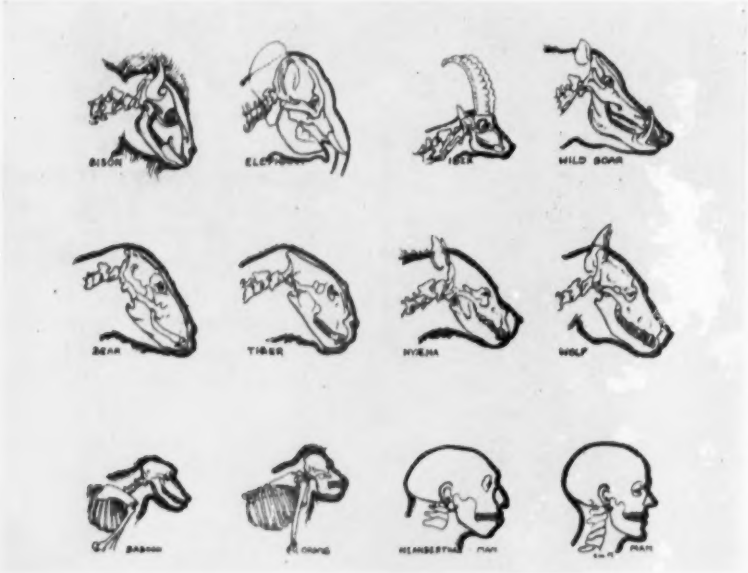
Other Functions Ascribed to Paranasal Sinuses

Lightening the Skull.—A suggestion as to the function of sinuses is that their presence lightens the skull, and particularly the anterior half, thus reducing the amount of work of the neck muscles.

This observation has apparently been made in regard to man only, a fallacious form of argument. Man is peculiar in maintaining an upright posture, unlike others of the primates, such as the gorilla, orang, chimpanzee, and gibbon; in all of these the attitude is forwardly inclined and slouching and not truly vertical similar to early types of man, such as the Rhodesian ancestor. All except man have strong neck muscles capable of holding the head in position under all conditions. It is only modern man whose head is more or less balanced on occipital condyles situated in the middle of the skull instead of at its posterior extremity, as in most four-footed mammals, as pointed out by Wood Jones (Fig. 8). Various degrees of forward migration of the condyles are to be seen in members of the primates.

It is true, as Causey and Stanfield have demonstrated, that if paranasal sinuses are present the weight of the anterior half of the skull is less if these spaces are filled with air than if they were occupied by cancellous bone. There is no dispute of this

Fig. 8.—Poise of the head. The illustrations show the forward migration of the occipital condyles in apes and man; the head in the latter is almost balanced on the vertebral column and requires little muscular support.



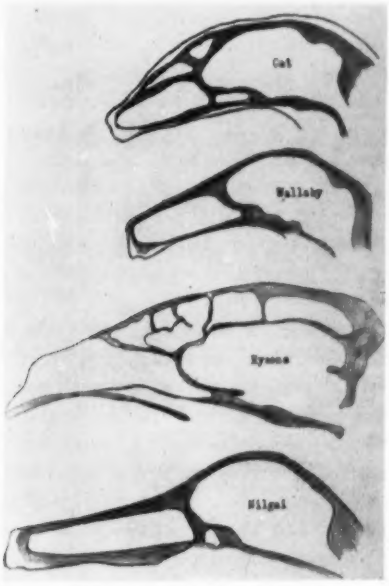


Fig. 9.—Relation of frontal sinus to cranium and nasal fossa. Sagittal section of head of cat (Felis domestica), wallaby (Macropus wallabatus), hyena (Hyaena), and nilgai (Boselaphus). The sections show the relative sizes of the cranial and nasal cavities in cat and hyena. The excavation of the sphenoid bone is also illustrated.

practical observation, but the deduction must not be drawn that the sinuses have been evolved purposely to lighten the skull.

Not only are the neck muscles developed to a degree sufficient to maintain the poise of the head, but in bulls they are strong enough to lift a horse and rider. Numerous examples could be given of provision of musculature adequate for its work, as in elephants, which lift tree trunks, and in wrestlers amongst man.

If the construction of frontal sinuses is studied, it is found that they appear as an upper story, superimposed above the nasal fossae and cranium. The additional bony walls so required add weight to the skull instead of lightening it (Fig. 9).

Humidification.—The various sinuses are so isolated from the respiratory air currents that any moisture they contain could not be of direct use for humidification of the nose or respiratory tract; again, the lining mucosa has a very poor blood supply and is only sparsely supplied with mucous or serous glands. It is possible, however, that such transudate or secretion as they supply can be of use in the immediate neighborhood, that is, in parts of the sinuses.

The various sinuses are lined in greater part by ciliated epithelium and this requires moisture, acquired from local secretion. But when the olfactory frontal and sphenoidal sinuses are considered, it will be realized that efficient humidification of contained air is also of advantage for the entrapping of olfactory molecules. It would appear that the frontal and sphenoidal air spaces unoccupied by ethmoturbinals may contribute a quota of moisture, which, entering the olfactory part of the respective recesses at their posterior ends, helps in the deposition of olfactory molecules carried in by diffusion of air. Assistance may be given to ciliated epithelium in certain species, and particularly in man, by the secretion escaping from ethmoidal and maxillary sinuses.

Phonation.—It has been suggested that air sinuses have a vocal function, acting as resonators and thus modifying or amplifying the sounds produced at the glottis; this argument has been applied particularly to man.

Without going into details it will be obvious, by referring to the various tables, that there is no relation between the presence or absence, or the size, of paranasal sinuses and the voice. The domestic cat, for instance, has a loud voice of wide range, but only a small volume of unfilled sinuses; the giraffe, with enormous frontal air spaces, is usually silent.

Conservation of Warmth.—It has been suggested by Proetz that air spaces, and particularly the maxillary, act as insulators to prevent loss of heat from the nasal fossae. It does not seem that this was the reason for which they were evolved. For in species which require the greatest degree of conservation of heat or of warming of air, so as to increase its carrying power of moisture, the heating apparatus takes the

form of an elaborately branching maxilloturbinal body; the great area of thin mucosa lying over a most extensive system of blood spaces is capable of giving up much heat and also of retaining much of the warmth carried in the expiratory air stream (Fig. 5, right). The maxilloturbinal of various animals, for example, rabbits and cats, is covered with a truly stratified epithelium arranged in two layers of cells; underlying the mucosa is an extensive system of vascular spaces under the control of the sympathetic nerves and capable of emptying or filling with blood. Radiation from this large blood volume is but little impeded, and heat will be given off readily.

The thinness of the epithelium allows transudation of fluid at the same time, to moisten the warmed inspiratory current of air. A constant supply of heat and moisture from this specialized epithelium, by virtue of the blood circulating beneath its surface, offers a far more efficient means of air conditioning than the mere conservation of warmth in maxillary sinuses; it is more profitable to have large maxilloturbinal bodies, filling the anterior part of the snout, than hollow air spaces (Fig. 5).

It has further been suggested that sinuses, presumably the sphenoidal, might protect part of the base of the brain against the impact of cold inspired air. In the first place, the air current at the back of the nose is not cold, and, in the second, the distribution of the sphenoidal sinuses among species is too erratic to have a purposive function in this direction.

Growth of the Face.—Proetz thought that the development of the human frontal and maxillary sinuses might be designed to assist forward and downward growth of the face.

The evidence of comparative anatomy shows an absence, in a vast number of animals, of both of the sinuses referred to, and the snout is nevertheless enabled to grow forward, sometimes to a considerable length. The baboon, amongst primates, has a long snout but no maxillary sinuses (Tables 2 and 3).

The development of frontal sinuses in the human subject is very irregular, and the rhinologist is unable to decide whether any are present unless radiographs are taken; those persons with only a single frontal sinus, or none at all, do not appear to show deficient facial growth.

The explanation given earlier, that the maxillary sinuses are unwanted air spaces, seems preferable to that which ascribes a purposive function to them.

149 Harley St. (W.1).

Congenital Microtia and Meatal Atresia

Observations and Aspects of Treatment

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Material, Sex, Side Affected

The material consists of microtias and meatal atresias found in patients admitted to the University Oto-Laryngological Hospital at Helsinki from the beginning of the year 1951 to the end of February, 1957. The total number of patients observed and treated was 74, males numbering 50 and females 24.

The observations were made and the cases evaluated on the basis of degree of microtia. In determining this degree I have followed the gradation of Marx, which is the most widely accepted one, also used by Altmann, a well-known investigator in this field.

We thus divide our subjects into three main groups: Grade I, Grade II, and Grade III. The first group, Grade I, included all subjects with distinctly malformed auricles, with smaller size than a normal outer ear, showing, however, most of the characteristic features of the auricle. To this group were added a few patients with a normal pinna but lacking an ear canal. The total number of subjects was 24.

The second group, Grade II, consisted of 45 subjects. The rudimentary auricle in most was very characteristic, consisting of a low, oblong elevation, hook-formed at the cranial end corresponding to the helix. There was a complete atresia of the canal.

The third group, Grade III, comprised only five subjects. The auricle was more defective still, showing only a part, often a malformed lobule, while the rest of the pinna was totally absent.

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Table 1 illustrates the distribution of the male and female subjects within the three groups. There is a distinct male preponderance, the ratio of males to females being 50:24. It is also perceived that Grade II is significantly the most frequent malformation.

TABLE 1.—*Congenital Microtia: Sex Distribution*

Grade I		Grade II		Grade III	
♂	♀	♂	♀	♂	♀
17	7	29	16	4	1

Table 2 classifies the cases according to the side affected. The figures differ from the previous table because some (eight) subjects had bilateral malformations. This applies to Grades I and II, whereas the subjects belonging to Grade III had only unilateral microtia. In all there were 49 right-sided and 33 left-sided malformations. However, this predominance of the right side is distinct only in Grades I and III. In Grade II the difference is considerably less convincing.

TABLE 2.—*Congenital Microtia: Side Affected*

	Grade I		Grade II		Grade III		
	R	L	R	L	R	L	Total
Total	17	11	27	22	5	5	82
	28		49				
Total	R49		L33				

The age distribution in the material appears in Table 3. There were only 13 adults among the 74 patients. Teen-agers numbered 22. The rest, more than one-half, were brought to treatment before having reached 10 years. The youngest child was 1 year 5 months. I would have preferred

TABLE 3.—*Congenital Microtia: Age Distribution*

	Grade I		Grade II		Grade III		Total
Age, Yr.	♂	♀	♂	♀	♂	♀	
1–4			4	1			5
5–9	11	3	10	8	2		34
10–14	4	2	5	2			13
15–19	1	1	5	2			9
20–30	1	1	5	3	2	1	13
Total	17	7	29	16	4	1	74

to delay the surgery, but at the parents' urgent request the correction was undertaken. The four other children under 5 years of age had all completed their 4th year.

The question as to the suitable age for surgical treatment merits attention. Two points should be considered: first, cosmetic correction; second, the desirable hearing improvement. This latter consideration favors postponement of the operation preferably until the age of 15. As the surgery can be done with local anesthesia at the age of about 20, this would make it possible to check the hearing during the operation and to observe improvement or failure in this respect. The surgical procedure might then be modified or changed according to the finding. Cosmetic correction, however, is desirable earlier. It should be performed before the child enters school to avoid teasing and mockery on the part of schoolfellows. This may happen even at preschool age in kindergarten. This reason would favor operation at 4 to 5 years. I shall return to this question at the end of this paper.

Pneumatization

There seem to have been few reports based on systematic comparison of the pneumatization of the mastoid process and of the temporal bone in cases of microtia. Most authors state that there is no evidence of a hereditary factor in the majority of the microtia cases. According to Altmann and Hagen, there probably is a local damaging cause in cases where the tympanic cavity and the neighboring pneumatic cells are poorly developed but the Eustachian tube, antrum, and the cells of the mastoid process have attained a normal development. The nature of the factor has remained unrevealed up to this time. The above condition shows that the different parts of the aerated system in the temporal bone may, at least to some extent, develop independently of each other. On the other hand, it is extremely rare to find a normal middle ear in cases with meatal atresia.

It is of interest to compare the degree of microtia and the extent of pneumatization in the present material. For this purpose roentgen films were taken in all but one case, in which it was inadvertently omitted. These examinations were made in the roentgen department of the hospital by Dr. C. J. Sjöblom, chief of the department. In all the cases two projections were regularly used: the Runström II, the same as that called in German "steile Schüller Aufnahme," and the symmetric axial projection for both ears. In the first the patient lies in ventral position. The head is turned entirely to the side. The cross of the skull table is placed 1 cm. posteriorly and 1 cm. caudally to the external auditory orifice. The roentgen tube is turned to the position +35 degrees, which means that it is moved cranially and then turned 35 degrees caudally. The rays thus enter from the opposite parietal region. If the patient is quiet, the exposures are taken stereoscopically. The opposite side is dealt with in the same manner. In the symmetric axial projection (also termed Runström IV) the patient lies supine with the head bent backward. The central ray traverses in the frontal plane of the external auditory meatuses.

In isolated cases some other projections were used. Among these may be mentioned

a symmetrical anteroposterior tomographic examination.

The Runström II projection is the best for evaluating the extent of the pneumatic cells. In the axial projection film the external meatus, the attic, and the ossicles are best visualized.

There is no standardized classification for the different degrees of pneumatization. In this investigation the following gradation is used: (1) large, extending outside the borders of the mastoid process; (2) medium, the whole or almost the whole mastoid being pneumatized; (3) small, the cells occupying chiefly the area between the sigmoid sinus and the border of the middle cranial fossa, thus filling the space behind and around the antrum, but not extending to the lower half of the mastoid; (4) scanty, with a few small cells in the base of the mastoid, mostly in the neighborhood of the attic and antrum, and (5) lacking. This classification is almost the same as that followed by Seppälä in his study of 1524 recruits of 20-21 years of age. Table 4 classifies the cases with different grades of microtia according to these degrees of process have attained a normal development. pneumatization. The Grade I group consists of 24 patients, of whom 4 had bilateral atresia. One of the patients, a girl of 6½ years, in fact had no microtia but bilateral atresia. A sister of hers, 9 years of age, had unilateral atresia and microtia of first degree. The elder sister had a small pneumatization on the affected side, the younger showed on one side total absence of cells, on the other a very scanty pneumatization. A scanty or lacking cell system was found in this group in nine cases, representing 32%. Conversely, a large or medium-sized cell system was present in 12 ears, making 43%.

Also in the Grade II group four patients show bilateral malformation. The group with scanty or lacking cell system comprises 17 ears, i. e., 34.7%. Correspondingly, the ears with large and medium pneumatization account for 40.8%. When these figures are compared with those of the Grade I group, the difference is only slight. However, both the increase of the number of cases with lacking pneumatization and the decrease of good pneumatization indicate a tendency for the cell system to diminish parallel with increasing outer malformation. It must be admitted that the difference is too small to be significant. But the Grade III group shows clearly the connection between the degree of malformation and the development of pneumatic cells. The subjects belonging to this group are few, five only, but the one placed in the group with scanty pneumatization also shows cells so indistinct that the ear might almost with equal right belong to the lacking group. On the opposite side this patient had a medium-sized cell system.

If one surveys the material as a whole, the cases with a scanty or lacking cell system account for 38%. To obtain an opinion on the significance of this figure one ought to compare it with material consisting of only healthy ears. Such material is very difficult to find and hardly ever observed in this respect. The above-mentioned material of Seppälä, however, meets the requirements in many respects. The groups of "strongly arrested" and lacking pneumatization together represent a percentage of nearly 25. Compared with the figure obtained in the present material, 38%, there is a distinct difference. Thus clearly more than a third of all the ears with microtia show a defective development of the air-cell system against only a fourth in normal material. In Grade III microtia aerated cells seem to be almost totally absent.

Attic

In an estimation of the cases of microtia from an anatomical and physiological point of view, the attic, containing the auditory ossicles, is one of the most important parts of the middle ear. There is a great advantage in having preoperative knowledge of the main features of this region. Therefore it is essential to try to get as good

TABLE 4.—*Congenital Microtia and Pneumatization*

Degree of Microtia	Degree of Pneumatization						
	Large	Medium	Small	Scanty	Lacking	Not Stated	Total
Grade I	3	9	6	2	7	1	28
Grade II	2	18	12	11	6		49
Grade III				1	4		5
Total	5	27	18	14	17	1	82
	39%		22%	38%			

roentgen exposures as possible. When presenting our findings we first examine the roentgen films. The size of the attic serves as a good reference point. Table 5 surveys the whole material.

A medium-sized attic was found in 8 cases of Grade I, making 28.5%, but in only 16% of the 49 cases of second-degree microtia. A small attic was almost equally common in both classes (32% and 36% respectively). A very small attic was exceptional among the Grade I cases. In the Grade II group it occurred in five instances (about 10%), but in the severest degree of microtia we found it in three cases out of five, which accounts for 60%, if calculation percentage on such a small number is justifiable.

Although the axial projection used here must be considered very good and suitable for visualization of the attic, it did not in every case reveal the true state. In three cases the attic could not be seen on the film, yet in each of these it was found at operation. In such cases there is surely an anomaly in the construction of the temporal bone, in which a massive osseous part of the bone covers the small cavity of the attic. Two cases are marked "?"; in one the area concerned was too hazy to allow any evaluation; the other one was the one in which roentgen examination was omitted by mistake.

As already stated, some authors stress the independent evolution of the pneumatic cells and the tympanic cavity. We want to mention here Altmann, Rüedi, and Eckert Moebius. In our material it is possible to compare the development of the cell system and the attic. In the group of third-grade microtia there seems to be a correlation in this respect: in each of the four cases with lacking pneumatization the attic was minute in size. In the other groups an irregularity was observed. In Group I lacking pneumatization was associated with a tiny attic only once, whereas in four cases with cell system lacking the attics were "small." As a small attic can be found with cell systems of highly varying extent, this finding is of no significance. Irregularity may also occur in the Grade II group. For instance, in three cases with medium pneumatization the attic was very tiny in two, and in one it could not be distinguished. This investigation thus seems to corroborate the assertion that the cell system and the tympanic cavity proper develop independently of each other.

Ossicles

We again wish to give first an account of the inspection of the films. Table 6

TABLE 5.—*Congenital Microtia and Atresia: Size of Attic*

Degree of Microtia	Size of Attic						
	Medium	Reduced	Small	Very Small	Invisible	?	Total
Grade I	8	10	8	1	—	1	28
Grade II	8	14	18	5	3	1	49
Grade III	1	—	1	3	—	—	5
Total	17	24	27	9	3	2	82

TABLE 6.—*Congenital Microtia and Atresia: Auditory Ossicles in Roentgen Film*

Degree of Microtia	Distinct, with Joint	Distinct, Joint Invisible	Clumpy Formation	Indistinct Condensation	Invisible	?	Total
Grade I	3	6	8	9	1	2	28
Grade II	1	12	6	22	7	—	49
Grade III	—	—	1	3	1	—	5
	4	18	15	34	9	2	82

shows that it is actually possible to see the ossicles in the majority of the cases. According to the distinctness of the features, the findings are divided into six categories: (1) distinct with visible incudomalleolar joint, (2) distinct but without visible joint, (3) a clumpy formation in place of ossicles, (4) indistinct shadow or condensation, (5) ossicles invisible, and (6) evaluation impossible for different reasons.

It is interesting to notice that it is frequently possible to ascertain the existence of the ossicles. The figures in the first three groups (including "Clumpy Formations") mostly correspond to the real state of things. Moreover, as we shall soon find in the category "Indistinct Condensation," the majority of the figures represent real shadows of the ossicles. This applies of course only to the malleus and incus, whereas the stapes is too gracile to appear in the film. In Table 7 the findings are compared with the roentgen examination.

In the first group, with a distinct joint, the ossicles were found in each case. But in the next group, with a distinct shadow of the ossicles, the attic could not be found in two cases and in two others the ossicles were not detected although the cavity was there. It is not surprising that such findings were more numerous in the group with indistinct shadows of the auditory ossicles. More surprising is the fact that in the group where the ossicles could not be traced in the film (nine cases), they nevertheless were present in more than half the cases (five). In the whole material the attic in 12 cases either appeared very small on the film or was invisible. No attic was found at the operation in five cases, and in two more cases the cavity was empty, and so the ossicles were not found in seven cases. In the remaining four the ossicles were found at the operation.

The above, of course, applies only to the malleus and incus or to the fused malleus-incus, better described as undivided corresponding part of the original Meckel's cartilage. But the shape and the mutual connection of all the three bones is equally interesting as the sole presence of these ossicles. We must admit at once that in the

TABLE 7.—*Congenital Microtia and Meatal Atresia: Comparison of Findings with Roentgen Examinations*

Degree of Microtia	Auditory Ossicles*																
	Distinct, with Joint			Distinct, Joint Invisible			Clumpy Formation			Indist. Condensation			Invisible			?	Total
	+	0	$\bar{0}$	+	0	$\bar{0}$	+	0	$\bar{0}$	+	0	$\bar{0}$	+	0	$\bar{0}$	+	
Grade I	3			3	1	2	5	2	1	6	2	1	1			1	28
Grade II	1			11	1		6			19	2	1	4	2	1		48
Grade III								1			2	1			1		5
	4			14	2	2	11	3	1	25	6	3	5	2	2	1	
Total	4			18			15			34			9			1	81

*+ found; 0, not found; $\bar{0}$, attic not found or not opened.

living subject, in whom we must avoid all damage to the anatomical condition in order to conserve the physiological function, it is not possible to observe the numerous interesting details which may be seen in the autopsy material, especially when examined by microscope. We must be content with much more restricted observations, often hampered also by the smallness of the unsufficiently developed cavities. Some detailed observations are illustrated in Table 8.

A real joint between the malleus and the incus was noted in 21 cases. In these the head of the malleus could not always be wholly visualized. Nor was it possible in most of these cases to get a perfect conception of the existence of the manubrium. When present it was often fixed to the atresia plate, or in a few cases to the defective drumhead. Sometimes the handle was atrophic and short. An "incus without malleus" is distinguished by its shape from a "malleus-incus." It is on the whole more like an ordinary incus, except for the missing articulation surface. The mass of a malleus-incus is distinctly greater. This fused ossicle seems to be the commonest formation. In Grade II microtia it is present in nearly half the cases, whereas in Grade I it is found in less than a third. Conversely, an incudomalleolar articulation, i. e., separate ossicles, was found in microtia of first degree in a third of the cases and in microtia of second degree in slightly more than a fourth. Although the difference is not very great, it points to a parallelism in anomalous development of the ossicles and the external ear.

The state of the stapes is the most difficult to examine. The tympanic cavity, the mesotympanum, is often very narrow, which is quite understandable because of the very frequent presence of an atresia plate. The use of a burr in this narrow space is risky. Luxation of the ossicles, damage to the incudostapedial articulation and to the facial nerve are potential dangers. However, the stapes was discovered in 14 cases, although of course for the most part it could not be seen wholly. It may be mentioned that even the tendon was seen in two cases and both crura were seen once. Mostly, however, only a part of the stapes could be discerned, often the posterior crus. In some instances real inspection was not possible, but palpation with a fine probe established its presence. In nine cases the mobility of the ossicle in the oval window was confirmed. Distinct fixation was established by palpation in three cases. In the remaining two notes are lacking. However, the impression was that fixation of the footplate was very rare. The incudostapedial articulation was often concealed by the mucosa. In one case there was a mucosa-covered thin cord attached to the stapes in place of the long process of the incus. In two cases the knob of the stapes was distinctly discerned. Once the niche of the oval window was found empty.

The impeded sound conduction in the cases of microtia is due not only to the atresia of the external meatus and the osseous atresia plate in place of the drumhead but also to the differing conditions in the middle ear cavities. One of these factors is fixation of the malleus and incus or the fused malleus-incus. This was found in 11 cases in the attic. The immobile malleus was attached to the bony wall in three cases, of which one belonged to the Grade I group and two to the Grade II group. The incus was fixed in two cases, once in each group. Both ossicles were fixed in two instances and the combined malleus-incus in four. Fixation may have occurred in some additional cases which remained undiscovered, possibly owing to release of the ossicles by the simple opening of the attic. In the

TABLE 8.—*Congenital Microtia and Meatal Atresia: Observations on Auditory Ossicles in Eighty-one Cases*

	Grade I	Grade II	Total
Incudomalleolar joint	9	13	21
Small separate rudimentary caput mallei	3	4	7
Handle of malleus	1	6	7
Incus without malleus	2	6	8
Malleus-incus	8	22	30
Stapes	2	12	14

majority of these cases, however, these two larger ossicles were mobile. Naturally it was not possible to judge if this mobility was of normal extent.

Tympanic Cavity

For the reasons already presented, the observations on the tympanic cavity are incomplete. In the majority of cases the tympanum was small. In quite exceptional cases there was a record of comparative spaciousness. In three instances there was no tympanic cavity, although the attic was found, once in Group II and twice in Group III. The lining mucosa of the mesotympanum was mostly thin, resembling a normal covering. In a few cases a thickened mucous membrane covered the walls of the narrow cavity. The area most difficult to inspect was the posterior part of the mesotympanum. Thus the niche of the round window was seen only once. The orifice of the Eustachian tube was not regularly palpated. In some cases the mesotympanum was not opened.

The normal place of the tympanic membrane was mostly occupied by compact bone. In 10 cases an "atresia plate" was seen. The thickness in most cases was estimated at more than 1 mm., often at 1.33 mm. Six of these belonged to the Grade I group and four to Grade II. A membranous drumhead was found in five cases, twice in the Grade I and twice in the Grade II group and once in Grade III. The membrane generally occupied the lower half of the ordinary site of the drumhead. In one case the manubrium was attached to it.

External Meatus

There is not much to be said about the external canal. In the present material atresia was complete in all but three cases, two of first-degree microtia and one of third-degree microtia. In the last mentioned, there was a stenosis, very narrow at the middle but enlarging in the most medial part, which was closed by the tympanic membrane. In the other two this innermost portion formed a small cavity closed outwards and inwards. It contained dark brownish thin cerumen. Such a cavity is generally revealed rather distinctly in the roentgen film.

Auricle

The present material contains only microtias and two patients without anomalies of the auricle but with atresia of the meatus. Cases with anotia, melotia, etc., are not included here. It is therefore unnecessary to describe the anomalies of the pinna more closely. The deviations from the ordinary types of the classification here accepted are very slight.

Auditory Function

Generally some hearing is present in ears with microtia. The ears with Grade I microtia as a rule show the best hearing. On an average, however, hearing is much impaired. Conversational speech is heard only at a short distance, from close to the auricle to 20-50 cm., exceptionally at a distance of 2-3 meters.

In 57 cases it was possible to take a pure-tone audiogram. In some additional instances the very young patients were able to respond to the examination, but the result showed that the graph obtained corresponded to the normal ear. In the majority the bone-conduction audiogram was on the 0-15 db. level and did not deviate from the curve of the sound ear. The air-conduction graph was in most cases horizontal or slightly rising toward the high frequencies. However, there were a great many cases with a slightly sloping end in the higher frequencies. An abrupt lowering was not encountered; nor was the higher end generally more than 20 db. lower. The course of the graph was mostly even, although dips were observed sometimes. Table 9 illustrates the various levels of air conduction in the Grade I and Grade II groups.

A great loss of hearing was seldom found, in 4 cases out of 57, i. e., in 7%. The most frequent level in both groups is the 50-55

TABLE 9.—*Congenital Microtia and Meatal Atresia: Pure Tone Audiogram, Air Conduction*

Db Level	Grade I	Grade II	Total
30-35	3	2	5
40-45	3	9	12
50-55	10	19	29
60-65	—	7	7
70-75	1	3	4
Total	17	40	57

db. level. Cases with a loss of 30-45 db. were relatively more numerous in the Grade I group than in the Grade II group. A loss of 60 db. or more was present only once in the Grade I group, whereas it was far from infrequent (10 cases out of 40, 25%) in Grade II.

In almost every case a gap between bone conduction and air conduction was present. Therefore in theory, improvement is possible. Naturally surgery is the only possible method for improvement.

Surgery of Middle Ear and Meatus

The surgical procedures in microtia and atresia of the external ear canal are concerned with two different problems, the malformed auricle and the anomalous middle ear. In the first case the question of cosmetic correction is to be solved, in the second the aim is improved function of sound conduction. Both are important. The question arises as to which should be given precedence. It seems almost natural that, in cases of unilateral microtia with a normal other ear cosmetic correction is of greater value for the subject. Again, a person with bilateral microtia and atresia having a considerable hearing loss certainly will profit more by improved hearing. The practical solution of this problem will be discussed later on.

Although it might be consistent to deal first with the surgery of the auricle, as this must generally be performed first during the operation if the whole operation is to be done in one stage, the middle ear operation will be described here first. It is reasonable because the findings in the middle ear have already been dealt with.

Before 1951 I simply tried to find the antrum and form a closed epidermis-lined canal to it. As regards improvement of hearing the result was not very satisfactory, although even this method gave positive results. The chances of improved hearing must be much greater if a membranous end of an artificial canal can be brought into contact with the chain of the ossicles. Thus, in this series of patients the first part of the operation aimed at the detection of the attic and the ossicles.

In this step of the operation the roentgen film serves as an important guide. From Table 5 it is seen that the attic was either very small or invisible in 12 cases. However, it may happen that the attic is not visualized in the film although in reality it is present. Thus, in five cases, or about 6% of the material, the attic was not discovered. Table 7 may give us a wrong conception, because the eight cases in which the attic was not opened include three in which opening was deliberately omitted for various reasons. It is very probable that cases of absence of the attic are relatively more numerous among those of third-grade microtia. In this group of five, the attic could not be discovered in two.

As a rule the trepanning was done with burrs. In a quite compact mastoid discovering of the attic can be very tedious and sometimes unsuccessful. In such cases a lesion of the facial nerve may occur, and the cavities of the inner ear are in danger of being opened. In four cases the facial nerve was encountered, but in only one the damage was serious. If the cavity of the attic is not found by cautious and careful exploration, it seems preferable to discontinue the trepanning. Many of these cases are from the beginning less favorable from the point of view of possible hearing improvement. Moreover, in one case the course of the facial was exposed over a long distance. The ordinary bend in the attic was lacking, its direction being rather straight downward from the fundus of the inner meatus. In one case the vestibule

was accidentally opened. The anatomy was irregular; the ossicles were not recognized; there was a deformed clumpy formation, which may have been the fused malleus-incus. If periantral or periattic cells are found, uncovering of the attic is much easier. In many cases the cavity of the antrum is minute or does not exist. There are other causes which may prevent good exposure of the attic and tympanum. At least in one case such a cause was the low site of the dura of the middle cranial fossa. We noticed this in some other cases, although it did not always interfere with surgery. This finding has been reported by many other investigators. Another irregularity, which may also be uncomfortable, is anteposition of the sigmoid sinus on the side with microtia. In our material this did not cause difficulties worth mentioning.

Opening of the attic and the tympanum must be done with utmost care in order not to dislocate or loosen the ossicles from their natural connections. On the other hand, they are in some cases wedged in the narrow cavity, in rare cases ossified to the walls. In such a case they must be freed by removing the surrounding bone step by step with a burr of small size. When the incus and malleus or the malleus-incus become movable, it is still desirable to disclose as much of the long process of the incus as possible without damage. Of course it is better if the incudostapedial articulation can be reached. It is then often possible to palpate the stapes, sometimes even to see it, and by these means to find out if it is fixed or movable in the oval window. As observed, this did not happen in the majority of the present material. This was due partly to unnecessary caution in the beginning, partly to the extremely small size of the tympanum, which made further disclosure too dangerous. The above findings are important when deciding upon further measures. Personally, my impression was that, even in most cases in which the incudostapedial articulation could not be exposed, the stapes was mobile. If so, further bone surgery in the middle ear cavities is unnecessary. Molding of an epidermis tube to substitute for the external meatus now follows. However, there still remains one unknown factor, the state of the round window. In my experience, it is extremely difficult to expose this area in cases of microtia. And, if it is obstructed, improvement of hearing by the surgical procedures known at present is almost futile.

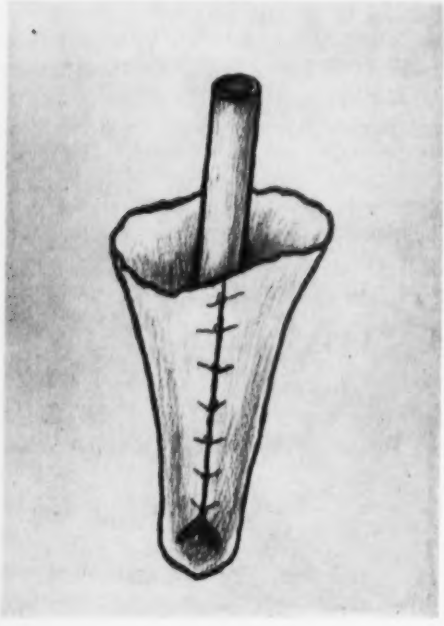
As for fenestration, advocated by some otologic surgeons (Ombrédanne, Siirala, Rüedi, among others), it surely can result in at least primary improvement in some cases. In our material we had two patients on whom a fenestration was performed. The first was a boy, 11 years of age with Grade I microtia. The stapes was found to be firmly fixed. The fenestra was made according to Lempert's method in the usual site. There was a primary improvement of air conduction from the 40 db. to the 15 db. level. Afterwards some deterioration took place. The second patient was a girl of 15 years who had second-grade microtia. As the improvement achieved by atticotomy and meatoplasty did not last, a fenestration was performed eight months later. The anatomy of the attic and the tympanum was extremely anomalous. No prominence of the horizontal semicircular canal was found. All landmarks of the facial canal were lacking. An attempt was made to find the horizontal canal lumen by removing bone from a comparatively large area of the medial wall. At last there resulted a hole into a small cavity, and the patient, locally anesthetized, stated that she felt vertigo. The site of the fenestra seemed to lie much more forward and cranial than was anticipated. A minute platinum plate was put close to the fenestra, and roentgen film taken the following day confirmed the right site of the fenestra. Very likely such difficulties would not be infrequent if fenestration were the regular surgical procedure in these cases (cf. Ombrédanne).

The epithelial coating for the new external auditory meatus was taken with a

dermatome mostly from the skin of the thigh. The thickness of the graft was about 0.8 mm. A funnel-shaped pouch was sewn with thin catgut. Into the closed bottom a thin plastic tube was fixed with a catgut stitch. The pouch with the tube inside was introduced into the bony canal, and the end of it was pressed cautiously against the ossicular chain in the hope that it would get attached to it by connective tissue. To keep the pouch in place it was packed inside with gauze. Prior to packing, the outer rim of the pouch was stitched to the outer skin (Fig. 1).

It was noticed that in some cases the coating tended to shrink so that the canal was shortened, and this was also confirmed by findings in a few instances where the cavity for some reason was reopened. Therefore I have lately modified this part of the surgery in six cases. The bottom of the pouch is left open, and the ossicles are covered separately with a smaller similar graft. It was hoped that this modification would ensure a more permanent restoration of hearing. Some of the results seem to meet the expectation.

Fig. 1.—Split-skin graft pouch for the external canal.



Plastic Surgery of Auricle

If the auricle is more or less normally shaped and there is only an atresia, no question as to plastic correction arises. An ordinary incision corresponding to the "endaural" one is sufficient. The rim of the pouch is fastened with thin silk sutures to the edges of incision. In first-grade microtia small corrections of the shape of the pinna mostly suffice and more extensive procedures should often be dispensed with, because an ideal result will seldom be attained. Only in exceptional cases did I resort to the methods employed in Grade II microtia.

Most cases of Grade II microtia were operated on by a method which I devised. The accompanying drawing (Fig. 2) illustrates the procedure. Behind the rudimentary elevation, which in most cases is convex anteriorly, a skin flap is separated. The nutrient base remains attached caudally. The anterior border is formed by an incision along the posterior attachment of the rudimentary helix. The posterior border of the flap is convex backward. It unites with the anterior border behind the cranial end of the rudimentary helix, forming an acute angle. The flap is freed from the underlying fascia down to its base. An anterior incision is made along the anterior attachment of the helix. This incision reaches neither to the upper end nor to the lower end. A fairly long buttonhole incision unites the anterior and the posterior incision under the middle portion of the helix. We performed the trepanning of the meatus and the middle ear cavities after these steps. Then the helix was sutured to the incision for the posterior border of the flap and became convex backward. The foresail-shaped flap was drawn through the buttonhole under the helix and attached with absorbable surgical suture and with silk

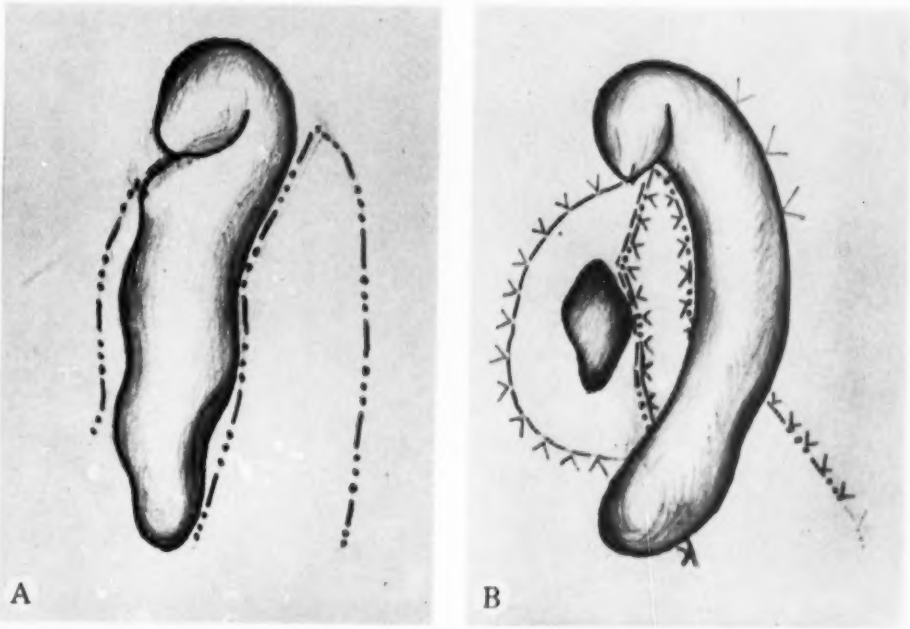


Fig. 2.—*A*, incisions are made in front and behind the rudimentary auricle. *B*, the skin flap is drawn from behind through the "buttonhole" and attached to the front of the auricle.

Fig. 3.—Grade II microtia. *A*, before operation. *B*, after auricle correction

Fig. 4.—Grade II microtia. *A*, before operation. *B*, auricle corrected, side view. *C*, auricle corrected, front view.

either to the anterior surface of the helix or to the skin in front of the newly made meatus. In the former alternative the posterior border of the graft pouch is sutured to the anterior border of the skin flap. There remains a canal from behind the helix to the anterior side of it under the lower portion of the helix. During healing it shrinks and is not seen without probing. A simple incision later can be performed to make this canal disappear if desired.

This plastic procedure frequently results in a reasonably good auricle (Fig. 3, *A* and *B* and Fig. 4, *A*, *B*, and *C*). This is the case especially when the rudimentary helix is more elevated. Its size generally differs considerably from that of the normal side. When the surgery is done at an early age, unequal size will be even more conspicuous after some years. Therefore it is in many cases necessary to enlarge such an auricle. The original helix can often be left to serve as an anthelix, the new helix being formed by the aid of a skin tube either from the upper region of the neck or from the unhairy skin left above the ear.

TABLE 10.—*Congenital Microtia and Meatal Atresia: Plastic Procedures Used in Different Grades*

	Meurman	Ombredanne	"Endaural" Incision	Various Corrections
Grade I	5	—	14	
Grade II	40	9	—	
Grade III	1	—	—	4
Total	46	9	14	4

Another plastic method, the one devised by Ombredanne, was also used, although less frequently. The rudimentary helix is divided in an upper and in a lower half. Both are loosened for some distance upwards or downwards respectively, turned backward and sutured into a short horizontal incision, the upper cranially, the lower somewhat caudally. This comprises the first step of Ombredanne's operation. We finished the bone surgery at the same stage. The third step of Ombredanne, the molding of the middle portion of the helix, was in our hands the second step. Also in Ombredanne's plastic operation, the constructed auricle often remains small in size and requires enlargement afterwards. Table 10 shows the primary plastic methods used in different grades of microtia.

Grade III microtia offers more difficulties. The plastic methods must vary a great deal according to the various malformed rudiments left. In many cases in which these are used for reconstruction, transpositions must be made. In addition, new parts must be made. Sometimes it may be practical to treat these as cases of anotia and construct an entirely new auricle (Fig. 5, *A* and *B*).

Postoperative Auditory Function

For various reasons it has not been possible to obtain postoperative pure-tone

Fig. 5.—Grade III microtia, with physiologic saddle nose. *A*, before operation. *B*, auricle corrected, nose improved.

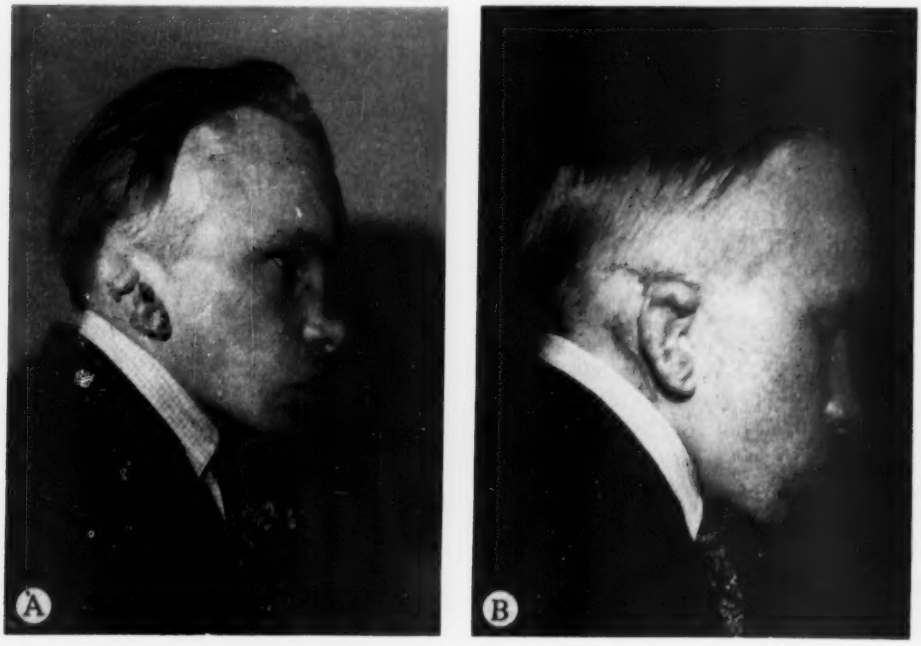


TABLE 11.—*Congenital Microtia and Meatal Atresia: Postoperative Pure-Tone Audiograms, Air Conduction*

Db. Level	Grade I	Grade II	Total
20-25	4	2	6
30-35	4	8	12
40-45	4	13	17
50-55	1	7	8
60-65	—	5	5
70-75	—	—	—
Total	13	35	48

TABLE 12.—*Congenital Microtia and Meatal Atresia: Postoperative Primary Improvement in Decibels*

Decibels	0	5	10	15	20	25	30	35	40>40	Total
Grade I	4	4	1	2	—	1	1	1	— —	14
Grade II	8	7	1	8	1	3	—	1	1 1	31
Total	12	11	2	10	1	4	1	2	1 1	45

audiogram was taken preoperatively. Table 11 contains 48 cases and shows the numeri- audiograms in all the cases in which an cal change in the distribution of the cases in the various decibel-level groups. Compared with Table 9, there are distinct differences. Table 9 included no single case with a loss of only 20-25 db. Now there are six ears with this practical hearing. The cases with 30-35 db. loss have increased from 5 to 12. The group of 40-45 db. loss has increased to 17 cases from the preoperative figure 12. The preoperative group 50-55 db. has diminished from 29 cases to only 8, and there are no longer any cases with 70-75 db. loss. As nine cases were omitted from the postoperative table, the figures permit no exact comparison, but a shift of the cases to groups with smaller db. loss is evident.

An attempt was made to determine the amount of improvement in both groups of microtia. In this record three cases from the previous record are lacking. Table 12 illustrates the improvement.

It must be admitted that the results are not excellent. In somewhat less than a half the improvement is practically nil. On the other hand, these congenital anomalies which differ considerably from a normal anatomical state cannot be expected to show a high percentage of improvement. Yet the improvement in some cases was quite considerable. For instance in a case with 70 db. loss hearing was restored to the 30 db. level.

As stated, the two preceding tables show the results of a primary improvement. In a number of these cases the hearing was further impaired later. At the present time we have not yet sufficient data. As already pointed out, we feel that by modifying the technique it ought to be possible to get a lasting improvement.

Results

Study of the present material consisting of 74 subjects having 82 maldeveloped ears, including 8 subjects with bilateral malformation, reveals the following data.

1. The material is composed of subjects with congenital atresia or high-grade stenosis in every case. In the vast majority the external ear was also malformed, presenting a microtia of first, second, or third grade. There were only four subjects who did not show a misshaped auricle but had aplasia of the external canal. The material was limited to these malformations, on purpose, greater developmental deviations, such as anotia and melotia being excluded. Cases of atresia without microtia and those of first-grade microtia are dealt with as one group, including 24 subjects of whom 4 suffer from bilateral malformation. The group of second-grade microtia has 45 subjects; here also four had a bilateral defect. Patients with third-grade microtia number only five, all with a unilateral defect.

The material shows distinctly that Grade II microtia is the commonest congenital malformation. It is almost twice as frequent as Grade I microtia. Grade III microtia is the least common, representing only one-ninth of the number of the second-grade subjects.

The hereditary factor could not be studied with accuracy. In most cases it could not be demonstrated. In the first group, however, there were two sisters, one 11 years of age, having atresia and unilateral microtia, the other 6½ years of age, with bilateral atresia

but no microtia. At least in this case a hereditary factor was present with considerable certainty.

2. The male sex predominates distinctly, the sex ratio being 50:24. The distribution in the three groups does not vary significantly.

3. Among the 82 ears observed the right ear was malformed in 49 cases and the left in 33 cases. Thus the right auricle was distinctly more frequently affected than the left one. This was clearly apparent in the Grade I and Grade III groups, whereas the predominance of the right side was only slight in the Grade II group.

4. The pneumatization of the mastoid was studied with the Runström II and Runström IV projections. A large and medium pneumatization was found in the Grade I microtia in 43%, in the Grade II in 40.8%. A scanty and lacking pneumatization was established in the Grade I group in 32%, in Grade II in 34.7%. In the Grade III group pneumatization was poor, in four cases lacking, and in one case scanty. A scanty and lacking pneumatic system was found in 38% of the whole material. In Seppälä's extensive material, 1524 young males, the corresponding figure was 25%. A poorly developed pneumatic system was thus distinctly commoner in the microtia subjects. Although the differences are too small to be convincing, the figures seem to show some parallelism between the grade of microtia and the development of the cell system: a high degree of malformation is more frequently accompanied by a poorly developed cell system than vice versa.

5. The size of the attic, as estimated from roentgen films, was medium in only 17 cases out of 82; in all the others it was more or less reduced. There were five categories: medium, reduced, small, very small, and invisible. There was no definite correlation between the attic size and the degree of malformation.

6. The auditory ossicles were found in 60 ears out of 81. In eight cases their presence is uncertain because the attic was either not discovered at operation or it was not opened. In some of these, however, the roentgen film revealed the ossicles so distinctly that there can be no doubt as to their existence. The 13 cases in which the attic was opened but no ossicles found certainly included some with ossicles present. This conclusion can be made on the basis of roentgen films, which demonstrated them distinctly. The controversy must be explained in some instances as due to faulty observation, in some to possible destruction, for instance by accidental boring of firmly fixed ossicles. There nevertheless remain a few cases (three) with nonexisting ossicles. On the whole, cases with ossicles lacking are certainly very rare. This applies to the malleus and incus or the fusion of these two ossicles. This investigation gives no definite answer as far as the stapes is concerned. The anatomic conditions rendered this examination difficult. However, the stapes was detected in 14 instances. All the findings, however, indicate that it was present in most cases. Here we could only once find an empty oval niche.

In about one-fourth of the cases the malleus and incus were joined by an articulation. This occurred in Grade I microtia relatively more frequently (about one-third) than in Grade II (somewhat less than one-fourth). Conversely, a fused malleus-incus was much commoner in the Grade II group (somewhat less than a half of the cases) than in the Grade I group (in less than a third, 8 cases out of 28).

Even when the two bigger ossicles were separated by a joint, the malleus was nearly always defective. A rudimentary head was usually present, but the manubrium was mostly lacking. In a small number of cases it was present but hardly ever of normal shape. The incus was often somewhat malformed but seldom showed defects.

Fixation of the auditory ossicles to the walls of the cavities was noted with certainty in 11 cases, i. e., in more than one-eighth of the whole material. In addition, there was fixation of the stapes in the oval

window in three cases. It is probable that fixation of the larger ossicles occurs somewhat more frequently than these figures reveal.

7. In most of the examined ears the tympanic cavity, the mesotympanum, was small. In three cases the mesotympanum was lacking although the attic was present. This was found only in groups Grades II and III.

Inspection of the posterior mesotympanum was difficult, and the niche of the round window could be seen only once. The mucous membrane of the mesotympanum was thin in the majority of the inspected cases; in the others it was hyperplastic. In place of the tympanic membrane osseous tissue was found in most cases. An atresia plate was present in 10 cases. A membranous drumhead was found in five cases, these distributed over all three groups.

8. Preoperative audiograms could be taken in 57 cases. The most frequent level of air conduction was 50-55 db. Most of the graphs were horizontal or slightly rising towards the high frequencies. A slightly sloping graph in the high frequencies was not infrequent. A very severe hearing loss (70-75 db.) was found in only four cases. A slight hearing loss was comparatively more frequent in the Grade I group. Bone conduction was generally normal or close to normal. In exceptional cases it was lowered. In only one case its decibel level was as low as 40 db.

9. The surgical procedures aiming at improved auditory function of the middle ear consisted of (1) trepanning a canal into the middle ear cavities with uncovering of the auditory ossicles and (2) making an epidermal coating for the canal and uniting its bottom to the ossicular chain. If the stapes is found fixed to the oval window, a fenestration of the vestibule or mobilization of the stapes may be indicated. As the stapes generally seems to be movable, a mobilization of the bigger ossicles is indicated and the connection with the new meatus must be established. A fenestration and mobilization of the stapes should be necessary only exceptionally.

In most cases the coating for the new external meatus was formed of a free-skin graft taken with a dermatome mostly from the thigh of the patient. The graft was sewn to a funnel-shaped pouch with a blind end. When introduced into the osseous canal, so that its bottom came into contact with the ossicles, its outer borders were sutured to the skin in the region of the orifice of the external meatus. In order to prevent a shrinking of the pouch, the bottom was later left open and the ossicles were covered with a separate similar skin graft.

10. In the same stage as the middle ear operation the rudimentary auricle was molded. I have devised a method specially adapted to Grade II microtia. From behind the malformed auricle a foresail-shaped pedicled flap is loosened with a caudal base and a posteriorly convex border. Close to the anterior attachment of the auricle a straight incision, two-thirds of the auricle's length, separates it from the underlying bone. The posterior skin flap is pulled under the auricle to its anterior side and attached there. The outer margins of the graft skin pouch are then sutured to the flap posteriorly and anteriorly to the skin in the tragus region.

11. Postoperative audiograms were taken from 48 cases belonging to the Grade I and II groups. A distinct shift upwards, to the smaller hearing losses, of the air conduction curves was observed. A level of 20-25 db., which was not present in the preoperative audiograms, did appear. An improvement up to 40 db. was reached in a few cases. Out of 45 cases 22 had improved primarily by 10 db. of more. Twelve remained at the original level and eleven showed an improvement of only 5 db.

Comment

The present material cannot be compared with previously published series in every respect. Perhaps that of Shambaugh, who also examined patients at operation, serves

best for comparison. He operated on 22 ears.

Ombrédanne has a large collection of material. He operated on 64 cases. In his collection the various degrees of congenital malformation are probably more represented than in my more uniform material. He has made numerous valuable observations. Pattee collected data on 75 ears observed by American aural surgeons. Of these, 64 had been operated on. His survey consisted of 29 bilateral and 33 unilateral cases. Accordingly, bilateral cases were distinctly more frequent than in my material. In Rüedi's material also the majority of cases were bilateral. He operated on 12 patients with bilateral and 1 with unilateral atresia. The temporal bones of one patient with bilateral atresia were examined histologically.

However, material which is histologically examined gives answers to many questions which must remain at least partially unsolved in living subjects. An investigation of great merit is that of Altmann who examined in detail the temporal bones of eight subjects. The total number of specimens was 13, five of the subjects having bilateral malformation. Some of these showed an anomaly of greater degree, such as anotia and melotia, which makes this group less homogeneous than ours. Altmann, moreover, surveyed 31 examined specimens published earlier by various authors.

A meticulous histologic study of one case has been published by Kelemen. The temporal bone of the 10-year-old girl was examined in complete serial sections. The malformation of the outer ear was third-grade microtia. There were changes in all the parts of the hearing organ: the external, middle, and internal ear. Complete absence of different organs occurred and also malformations and defective structures. To illustrate, we mention the following observations: Reisner's membrane and the tectorial membrane were absent. The modiolus was rudimentary. This also applies to all the ossicles in the middle ear. Conversely, the labyrinthine capsule had developed almost normally. Kelemen draws the conclusion that the etiologic factor responsible for the agenesis ceased to exist after the first two months of embryonic life. This shows how complicated malformations can become. They may depend on the time when the causative agent sets in. The different structures can develop independently side by side, at least to a certain extent, and produce various combinations of the malformed parts.

Fraser had one histologically examined case of his own and he reported the data on six cases from the literature. To these he added 15 clinically examined patients with microtia and meatal atresia. These were not treated surgically. The extensive literature on the subject cannot be surveyed here. A name which should not be omitted, is that of Alexander, who published reports of great merit, partly with Benesy, partly alone.

As to the genesis, our material does not bring any new facts. This much may be said, that a genetic factor was quite rare. As already mentioned, there were two sisters of whom one suffered from Grade I microtia and atresia, the other from bilateral atresia without malformation of the auricle. From the literature we see that a unilateral microtia generally is not hereditary. The present material seems to confirm this. Conversely, among the bilateral sufferers a hereditary factor is more frequently probable and often even established.

Among our cases we did not find distinct defects of the inner ear organs. In two cases the roentgen film showed a somewhat smaller cochlea on the affected side. One belonged to the Grade II group, the other to Grade III. In neither of these two cases did the audiograms show a hearing loss of perceptive type. In one case the bone conduction was depressed to the 40 db. level, which might mark a defective function of the cochlea. The slightly sloping curve in the higher frequencies is probably not a sign of defective inner ear function. It is probably due to some peculiar formations

in the sound-conducting organs. It is commonly held that the internal ear very seldom is the site of malformations in material like ours (cf. Ombrédanne).

As regards the predominance of the male sex and of the right side, our material is in concordance with the results of other authors (cf. Pattee). However, the group of second grade microtia does not show a significant difference between the right and the left side.

Systematic examinations of the pneumatic cell system in cases of microtia seem to be infrequent. Our results seem to point to a certain correlation between the development of the cell system and the grade of microtia in that a greater malformation is more often accompanied by a poor pneumatization. This is quite opposite to the conception of Alexander, who says in his monograph (p. 34) that the cases with congenital atresia generally show a distinctly large pneumatic mastoid process. The extent of the cell system on one side seems to be independent of that on the other.

From the literature it is difficult to form an opinion on the absence of the auditory ossicles. No figures are presented. We have come to the conclusion that this state must be very rare. But in our series this was proved in three instances. This applies to the larger ossicles. As for the stapes, at least the crura were lacking in one case. Although we established fixation of the stapes in three cases, our impression is that it is usually mobile, which is also the opinion of Shambaugh. About its shape, whether normal or not, we cannot express any judgment. In Altmann's material anomalies of the stapes were comparatively frequent, but as already stated, his material is more variable than the present one. This may also explain the findings of Ombredanne, who found four different malformations of the stapes and in addition also a complete absence of it.

As the bone-conduction audiogram was mostly normal or nearly normal and the air conduction graph in most cases is more or less horizontal or slightly rising, there was theoretically a possibility of diminishing the gap. We therefore cannot concur in Altmann's very reserved attitude concerning surgery. Much more do we agree with Shambaugh and Ombrédanne. On the ground that the ossicles are mobile or can be rendered mobile, we find a conservative procedure indicated, leaving the ossicles in situ and establishing a connection between them and the bottom of the reconstructed external meatus. We also agree with Shambaugh in rejection of a routine fenestration proposed by Ombrédanne. This method should be reserved for the few cases with confirmed stapes fixation. In our view, it is also unnecessary to remove the malleus and incus, as suggested by Pattee and House, when there is a possibility of rendering them mobile. The opinion of the earlier authors that the surgical procedures should be limited to a few cases is hardly in concordance with the efforts of otologic surgeons directed at diminishing hearing loss in different and various cases. This does not deny the fact that the methods for achieving a best possible result must be still further developed.

As early as 1947 Pattee suggested making the external meatus of a split-skin graft. He removed the incus and tried to apply the bottom of the skin pouch against the upper hiatus of the mesotympanum. It is easy to understand that such a procedure could not establish a very efficient connection with the stapes. Later, in his survey, he mentions two methods which brought a remarkable improvement. In one of them skin graft was applied against the capitulum of the stapes after the incus had been removed. The percentage of improvement rose to 90.5. In the other, the auditory ossicles were left in situ. There was improvement in 75%. In a later follow-up record the first-mentioned group had lost more of the preliminary postoperative improvement than the second group. However, he advises that the operation should be done in such a way that a secondary fenestration according to the method proposed

by De Graaf Woodman can be easily performed. It cannot be denied that a fenestration has frequently given very satisfactory results. Ombrédanne succeeded in obtaining a remarkable improvement of hearing in many cases. Siirala has published a successful case. Even Shambaugh, who does not advocate a fenestration as a routine method in these cases, has sometimes had good results from it. Both these authors placed a skin graft on the head of the stapes after removing the incus. Rüedi achieved a good to adequate primary hearing gain in 10 of 18 ears operated on by Pattee's method. Because the improvement was again lost in some, he recommends two-stage fenestration for uncomplicated atresia. In my opinion, the ossicles, when mobile or after having been rendered mobile, ought in most cases to be capable of transmitting the sound vibrations from a skin graft attached to them to the internal ear in a natural manner. The observations in Pattee's survey seem to confirm this opinion.

Correction of the malformed auricle is, at least in the cases of second- and third-grade microtia, equally important as improvement of hearing, perhaps even more important. Unilateral malformation in particular is a psychic incubus. It may be admitted that in the most cases the auricle which results from plastic procedures has not the shape of a normal pinna. A second trouble is the too small size resulting particularly from corrective measures in childhood. However, it is usually possible to obtain an outer ear which does not arouse much attention, and, if there is also improvement of hearing, the corrective operation has been justified and is a gain. The reasons for operating on these patients in early childhood has already been discussed. For a good cosmetic result, postponement of the surgery would be advantageous. At an early adult age the pinna can be formed large enough and given a rather good shape by the aid of an artificial subcutaneous implant imitating the peculiar features.

Such a postponement will seldom be chosen by the parents and by the patient himself when he has grown old enough to judge it. For the primary surgery we recommend the method of Ombrédanne and my own. Each of them has some advantages. It may be a matter of taste. We of course prefer our own method. In both, enlargement of the primary auricle will be indicated in many cases. When using my method the rudimentary helix often can be fashioned into an anthelix in the second step of the operation.

Summary and Conclusions

A study of 74 subjects with congenital atresia and in most cases microtia also is presented. The observations were made at the operation. The material includes 82 ears, as eight of the subjects had a bilateral malformation. The findings are in accord with those of many earlier investigators concerning a predominance of the male sex and of right-sided malformation.

The cases of atresia or high-grade stenosis of the external meatus show three grades of developmental anomalies of the pinna, classified according to Marx, as being of first, second, and third degree. Microtia of second degree is the most frequent type, even if other still more deviating anomalies omitted in this study are included.

The extent of pneumatization of the mastoid process bears some relationship to the grade of malformation: the third-grade microtia cases show a distinctly poor or completely lacking aerated cell system. Although the difference is slight, the arrested pneumatization in Grade II microtia is more frequent than in the Grade I cases. In the whole material a scanty or lacking pneumatization occurred in 38%, while in a comparative normal material the incidence of such cases was 25%.

In the great majority of cases the size of the attic and the mesotympanum was smaller than in a normal material, and in only 17 cases out of 82 was the attic of medium size.

In microtia of Grade I a separate malleus and incus were found more frequently than in microtia of Grade II. A clumpy ossicle—a fused malleus and incus—was found in 30 cases. It was distinctly more frequent in Grade II, 45%, than in Grade I, 28%. The larger ossicles were definitely lacking in only three instances. Wedging of the ossicles in the narrow cavities was noted 11 times but probably occurred in some more.

A stapes was probably present in the majority of cases. It was found fixed in the oval window in three instances.

The niche of the round window could be seen very exceptionally. More attention, if possible, should be paid to the round window region in the future.

The air conduction audiogram is mostly horizontal, sometimes slightly rising, sometimes slightly sloping towards the high frequencies.

The surgical procedures directed at the meatus externus and the middle ear cavities consisted in exposure of the attic and often the mesotympanum, freeing of the malleus and incus, formation of a coating of skin by a dermatome graft for the new meatus and bringing it into contact with the mobilized malleus and incus or fused malleus-incus. The rudimentary auricle was corrected in the same stage of the operation in 46 cases according to the method of Meurman and in 9 according to that of Ombrédanne. In Grade I cases an incision resembling the "endaural" was used 14 times. The Grade III cases required special plastic methods.

By this surgery the pure-tone air-conduction audiogram could be primarily improved by 10 db. or more in about 50% of Grade I plus Grade II.

A comparison of the results with those of some other authors is presented. The surgical procedures for atresia and microtia are considered. I am of the opinion that a fenestration should be used only in a few cases. Correction of the rudimentary auricle is desirable even at an early age.

Fredrikinkatu 20A.

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Stapes Mobilization in Otosclerosis

Personal and European Experiences

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Introduction

The present paper deals with the experience of stapes mobilization in Europe. It is of course impossible to give a complete account of all the relevant work done by European otologists. As far as I know, the first clinic to follow the suggestion of Samuel Rosen was the Oto-Laryngological University Clinic in Helsinki. I therefore find it justified to use our personal experience as basis for this presentation, supplementing it with data communicated to me by some European colleagues. I have at my disposal a series which is probably one of the most extensive in Europe, consisting of 379 cases up to the end of the year 1956.

It may be said at once that mobilization of the stapes in the beginning was not received here with equally great enthusiasm as in the United States. There has been a great deal of reservation which may be considered justified, but there has also been prejudiced suspicion which must be considered unjustified. However, interest of otologists has gradually increased. In our hospital we introduced the mobilization operation in April, 1954, and we had performed a few primarily successful operations, when Dr. Rosen himself, invited to the Nordic Otolaryngological Congress, demonstrated his method to us.

The original Rosen technique, working only through an ear speculum, aroused a well understandable enthusiasm because of its simplicity. It seemed to be easy and to belong to the minor surgical interventions. Yet working with only one hand, the other being used to direct the speculum, hampers the necessary manipulations considerably. Also the whole operating field mostly cannot be visualized at one time but necessitates changing the direction of the speculum. This technique may suffice as long as a simple pull only is required. But the anatomical construction varies, if not widely, yet sufficiently to prevent the tendon from being visualized, to say nothing of the crura and still more of the footplate. It is comprehensible that such half-blind working cannot satisfy a conscientious surgeon. However, it is surprising how poorly this side of the technique was discussed in the otherwise meritorious symposium of American otologists in the spring of 1956.

Breaking of the crura certainly is a very annoying experience for everyone who has had noticeable experience with this operation. This applies particularly to the original Rosen procedure but also to its modifications and many other methods. It has caused several proposals aimed at avoiding too strong a pull or pressure on the fragile crura. Even Rosen himself has shifted the point of attack to the footplate, calling this the "direct method." It may be remarked that even before Rosen's publication, loosening of the footplate had been proposed and described by me in the *Archiv für Ohrenheilkunde* in 1955, and still earlier I had presented this procedure at the West German Congress of Otolaryngologists at Konstanz in May of the same year, as was known to Rosen.

The afore-mentioned facts have given rise to several varying methods for mobilization.

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From the Oto-Laryngological University Clinic in Helsinki.

Lecture delivered in Baltimore on May 16, 1957, while serving as the Samuel J. Crowe visiting Professor at The Johns Hopkins University School of Medicine.

It is natural that the mobilization operation is in a stage of active development. Up to the present time we have not had a standard method which would guarantee the best possible result. We understand this better when we recollect the development of the fenestration surgery in which Julius Lempert finally established the main features of a successful procedure.

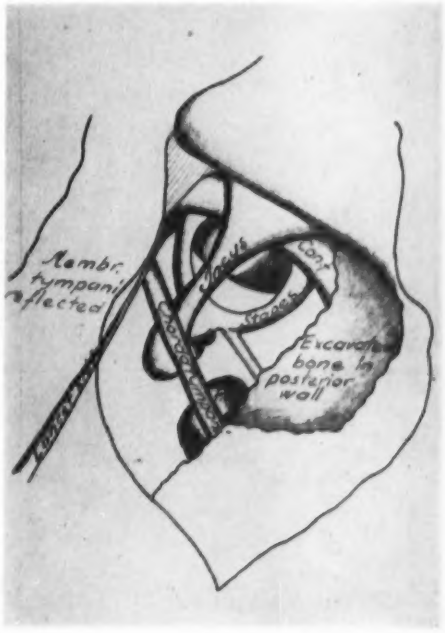
Having extensive material from a single clinic at my disposal, I consider myself justified in describing my technique at present, dealing also with the points in which it differs from the one originally used.

I may as well admit at once that the originally simple and minor surgical procedure of Rosen has turned in our hands into far more complicated surgery. Compared with the fenestration operation, it demands an even more meticulous technique. It is important to use an operation microscope instead of the originally proposed loupe, with which binocular inspection is often impossible. In addition, the binocular microscope of Zeiss offers excellent illumination and good facilities for checking the result with different magnifications. All this is very valuable.

Technique

Although we succeeded in a number of mobilizations by working only through an ear speculum, we soon found that excavation of the bony meatal wall in the posterior limbus with the curettes of Rosen was unsatisfactory. Stronger instruments were required, preferably a burr. But a burr would have been too voluminous within a speculum to allow simultaneous inspection. Therefore an endaural incision was used. A transverse incision parallel to the external border of the meatal orifice is made about 0.5 cm. inward from it, comprising 2/3 of the upper periphery and reaching to the bone. From the most cranial point an additional incision runs out of the meatus in front of the crus helicis. The margins of the latter incision are separated from the bone, not very wide apart, and a retractor is placed in position. Careful hemostasis is accomplished with diathermy. After this the "meatal cuff" is separated to the tympanic limbus and then from the sulcus in such a manner that the margin of the tympanic membrane is separated from the incisura Rivini down to 5 o'clock in the left ear. Now the lower tip of the long process of the incus and the chorda are generally visualized. However, the extent of the visible field varies considerably. For an unimpeded view of the stapes, of its tendon and the whole niche of the oval window, a large portion of posterosuperior bony meatal wall must be removed. The described approach allows the use of a dental burr and even makes it possible to avoid damage by the burr. The bone must be removed caudally to the orifice of the chorda and cranially to the base of the long process of the incus. In this way it is possible to inspect both crura of the stapes, in most cases down to the attachment to the footplate. Very often the footplate itself is visible between the crura (Fig. 1). It is often necessary to turn the head slightly to get a good view of the anterior crus,

Fig. 1.—The area exposed at operation.



which otherwise is behind the incudal process. When the margin of the drum is freed farther downwards, the round window region will be exposed to view. The findings in the region of the oval window vary considerably. Sometimes the footplate lies very deep, especially when the bony facial canal is more prominent than usual. The margin of the promontorial side can also be unusually prominent. The crura differ in direction. Mostly they are directed cranially, the angle varying. In rare cases they may be in a plane forming an acute angle with the horizontal plane. If the approach is not wide enough, the view of the operating field will be unsatisfactory. The manipulations will be difficult and their outcome cannot be checked adequately.

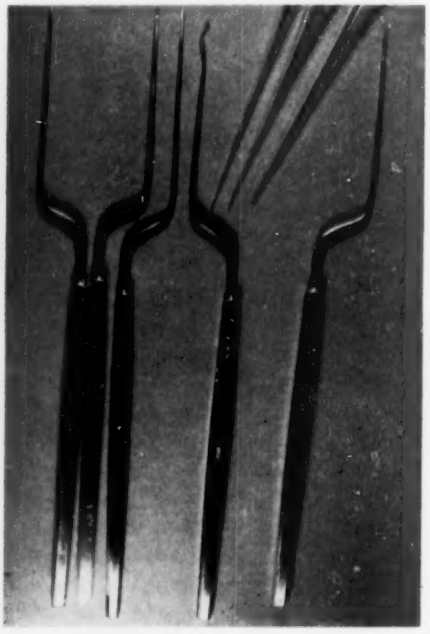
Because of the unsatisfactory exposure of the operative field in the original Rosen method, I designed a procedure in which a preliminary atticotomy was used to help to widen the approach. It undeniably offered a very good view of the oval window. And certainly there are cases in which it is superior to the present method. In this latter, however, a sufficient removal of bone between the exit of the chorda and the facial will assure a funnel large enough for necessary manipulations (Fig. 2).

A wide exposure also helps to reveal the gross pathology. Often the crura have been found fixed to the promontorial border of the niche. Sometimes they appear rough, owing to otosclerotic bone. In other cases the space between the crura is filled with bone or by an osseous disc. The thickness of the crura varies considerably. Thin crura warn against incautious working. It is in many cases possible to observe the condition of the footplate. Its tympanic surface is mostly slightly concave, but it may also be bulging when the bone is hypertrophic as a result of otospongiosis. In these cases the footplate is firmly fixed. I have also noticed prominent osseous foci in the margin of the window.

A set of instruments was designed for loosening the footplate (Fig. 3). The

Fig. 2.—Photograph at operation; incus, tendon, chorda, and both window niches visible.

Fig. 3.—Instruments, from left to right: mobilizators for left and for right ear, lancet knife, mobilizator of Rosen type, glass suction tubes of different calibers, needle-pointed sharp probe.



handles are bayonet-shaped in order not to interfere with good vision of the field. With a broadened short right-angle hook at the end, one checks the degree of fixation in the manner of Rosen. However, the point of attack is the ossified annular ligament. According to Guild, the ossification is in most cases strongest in the anterior periphery, and we therefore mostly begin the breaking of the focus there. A very slender and narrow double-bladed knife at the end of the bayonet handle is cautiously pushed between the crus and the margin of the window, or close to the crus junction above or beneath it. The same manipulation must sometimes be made close to the posterior crus. The knife is so narrow that it can be pushed between the crura for loosening the long inferior or superior margin of the footplate. Lately we have also used similar knives with saw-tooth edges in cases with very firm osseous foci (Fig. 4).

Careful hemostasis is important. For sucking up fluid and blood we use capillary glass tubes of different calibers. The thinnest must be so thin that they have room sufficient only for cleaning the surface of the footplate between the crura. These glass tubes have the advantage that the lumen is narrowest at the point. Consequently they are not occluded by particles or blood clots as easily as metal tubes with even caliber. The tubes are bent at an obtuse angle about 10 cm. proximal to the end. Close to the end is a small hole in the glass wall for weakening the suction power if necessary. When it is closed, the full power is operative.

Fig. 4.—Point of saw-toothed lancet knife, magnified.

Cautious working with these instruments requires ample time. Every hurried and careless movement must be avoided. Despite all caution and utmost care, fracture of a crus may occur. Loosening of a rigidly fixed footplate often takes considerable time, perhaps 15 to 20 minutes. This surgery is not a matter of a few minutes, but spending of sufficient time brings success much more frequently.

Material and Observation Time

In 1954, from April to the end of the year, 101 mobilizations of the stapes were made. In the year 1955 the number increased to 136. In 1956 the number was 142. Thus the total amounts to 379 mobilizations, the figure including also remobilizations. This material is not homogeneous, because the technique was changed in succession for the reasons already mentioned. During the first year the vast majority were mobilized according to Rosen's method; during the following year also the Rosen operations were most numerous, although a good many mobilizations were performed by the method of loosening the footplate. In 1956, however, the original Rosen operation was used in a minority of cases. In dealing with the material, this must be taken into account.

The preoperative audiograms were taken one day or a few days before operation. Generally this examination comprised a pure-tone audiogram, a Békésy audiogram, and a speech audiogram based on lists of Finnish bisyllables mainly corresponding to the spondees. In addition, the distance for

spoken and whispered conversation was determined. At the operation no audiometric examination was used except in a few cases, but the distance for conversational and whispered voice was regularly checked.

The first postoperative audiograms were mostly taken five to nine days after the mobilization. Whenever possible, the second audiogram was recorded about one month postoperatively. The successive examinations were then performed about three and six months after the mobilization, and then at an interval of one year and more, not quite regularly because the patients living far from Helsinki could not be compelled to return on fixed days. The follow-up categories were as follows: less than 100 days, 100-200 days, 200-300 days, 300-400 days, 400-700 days, and more than 700 days. The longest observation record at the time of writing is 1004 days. Table 1 classifies the cases by the severity of the preoperative hearing loss, the generally accepted gradation being used.

A number of patients were not checked within 100 days after the operation for various reasons. However, most of the patients were examined several times, and their hearing level could be followed for months and years, and thus possible changes could be revealed at fairly regular intervals. In Table 2 is shown only the longest observation time for every period group. In this way every case appears only once in the table. Consequently the sum of the observed ought to correspond to the total number of patients operated on. As will be seen, the difference is small. There were only a few (eight) patients who, for various reasons, could not be examined.

TABLE 1.—*Stapes Mobilizations 1954-1956: Cases Classified According to Shambaugh*

	A	B	C	Total
1954	64	29	8	101
1955	89	34	13	136
1956	94	46	2	142
Total	247	109	23	379

TABLE 2.—*Stapes Mobilization 1954-1956: Longest Observation Time*

	Number of Cases			
Observation Period, Days	Total	A	B	C
<100	173	112	55	6
100-200	60	39	17	4
200-300	35	24	9	2
300-400	34	22	10	2
400-700	41	32	7	2
>700	28	16	7	5
Total	371	245	105	21

Examination Method

Here we shall deal only with the pure-tone audiograms and leave the other examinations to a later date. In the pure-tone audiogram the bone conduction and the air conduction were checked in the following frequencies: 250, 500, 1000, 2000, and 4000. From the resulting figures a mean value was determined by adding together the five values and dividing the sum by 5. Our calculation is thus not directly comparable to that of many investigators who consider the three middle frequencies, 500, 1000, and 2000 cps, representative of the practical speech range. As the speech frequencies actually go beyond these limits both in the lower and in the higher end of the scale, we think that our method equally well meets the requirements of a true state. However, we have the impression that our mean values are somewhat lower than those calculated from the three frequencies mentioned.

By the aid of the mean values of the audiograms it is easy to follow the changes in hearing and check the gain or impairment. The cases have been divided into A, B, and C groups in the usual manner, as proposed by Shambaugh for the fenestration operation. The changes in air conduction form the best criterion of effect. Naturally it must be remembered that a shift from a slight hearing loss upwards close to the normal level can never attain an amount equal to that in a severe hearing loss. In the former the hearing may become better than in the latter despite a very high gain in decibels in the latter case. On the other hand, the latter shows more clearly the potentiality of the mobilization. In the following account we

TABLE 3.—*Gain or Loss in Hearing: Primary Results*

Year	Examination at<100 Days	Loss or Unchanged	Improved	Improved Per Cent
1954	44	30	14	32
1955	76	43	33	43
1956	127	36	91	72
Total	247	109	138	

are going to observe first gain and impairment.

Our measuring scale has been as follows: cases between a mean improvement up to 4 db. and a loss down to 5 db. have been considered unchanged. An improvement of 5 db. or more has been deemed a gain. This has been divided into groups 5-10 db., 11-20 db., 21-30 db., 31-40 db., 41-50 db., and >50 db. The highest noted gain rose to 54 db. Loss groups were divided into 6-10 db. and >11 db. We have found that this division has been justified by comparing the results with those of speech examination.

Our material shows a definite change during the three years we have used mobilization. This certainly is due partly to increasing experience but still more to changes in methods. This appears in the results in 1954, during which the Rosen method was the only one, in 1955, when the technique gradually changed though the Rosen technique was still predominantly used, and in 1956, when direct mobilization of the footplate was performed in the majority of cases (Table 3). Compared with 1954, the proportion of improved cases is more than double, (*32%* and *72%*).

For a hard of hearing person an improvement in audition is always valuable, even if the hearing level does not rise to that of "practical hearing." The greater the gain the greater is the direct profit. A slight rise from a preoperatively very low level naturally does not signify much. As stated already, the difference between the pre- and postoperative audiogram level is a criterion of the effect of mobilization. However, comparison of the postoperative hearing level with the normal average hearing level demonstrates the amount of hearing obtained. Considering that the gap between air conduction and bone conduction generally determines the extent of possible improvement, observation of the postoperative change of gap is important. Both these have been examined in the present material.

In order to obtain values somewhat more comparable with those of many other authors we have used in these determinations a somewhat differing method from that previously used. Only the best three of the five determined frequencies of the audiogram were considered. By this means the cases were divided into the five categories shown in Table 4. Here the primary postoperative result is indicated by the first postoperative audiogram. The figures differ from those in Table 3 because a great many of the postoperative audiograms were taken more than 100 days after operation. In all but the last of these categories there was a shift of the level upwards.

The Table shows that the best results were obtained in the group of A cases: only these reached the 15 db. level or higher, the proportion on the 20-30 db. level being almost double that in the B group. Those

TABLE 4.—*Postoperative Decibel Level: Primary Results*

Db. Level	A Cases					B Cases					C Cases				
	1954	1955	1956	Total	%	1954	1955	1956	Total	%	1954	1955	1956	Total	%
-15	5	6	4	15	6.1										
20-30	27	21	49	97	39.3	5	8	10	23	21.2	1	1	—	2	8.7
35-45	1	18	30	49	19.8	6	7	17	30	27.5	1	2		3	13.1
50-	9	5	4	18	7.3	3	1	6	10	9.2	1	2	—	3	13.1
No Result	22	39	7	68	27.5	15	18	13	46	42.1	5	8	2	15	65.1
Total	64	89	94	247		29	34	46	109		8	13	2	23	

TABLE 5.—*Comparison of Bone Conduction and Postoperative Air Conduction: Primary Results*

Group	1954		1955		1956		Total	
	No.	%	No.	%	No.	%	No.	%
I	12	11.8	21	15.4	23	16.2	56	14.7
II	29	28.6	29	21.3	64	45.0	122	32.3
III	18	17.8	22	16.2	32	22.5	72	19.0
IV	42	41.8	64	47.1	23	16.2	129	34.0
Total	101		136		142		379	

Groups: I, loss of postop. AC 0–10 db. > preoper. BC
II, loss of postop. AC 15–20 db. > preoper. BC
III, loss of postop. AC 25– db. > preoper. BC
IV, No result

without a positive result account for 27.5% in Group A and 42.1% in Group B. An increase in good results in 1956 is evident in the two best groups. This applies to both A and B cases, and, as will be demonstrated later on, is due to the "direct" mobilization method.

The decrease in the "gap" between bone conduction and air conduction is illustrated in Table 5. The cases are here divided into four groups, I to IV, according to the primary postoperative state.

Group I includes the cases in which fixation of the stapes was slightest. The percentage obtained in the different years shows no appreciable difference. This suggests that the different methods used for mobilization are equally efficient. Group II probably contained a greater number of rigid fixations. A remarkable difference is noticed between the results in 1956 and those in the two preceding years in favor of the first mentioned. Likewise the cases with no results were distinctly fewer in 1956 than earlier. Thus both the above tables are consistent in many respects.

Maintenance of Improvement

It is important to know whether the improvement is maintained after operation. A great number of cases were examined audiometrically within the first 20 postoperative days and as many as possible also within the successive period up to 99 days after the operation. In each of these years the percentage of improved did not change noticeably. Also the groups examined during the time of 100-200 days postoperatively still contained the same percentage of improved or a slightly higher. From then on there are variations, but in the main the percentage of improved drops. Those examined within 300-400 days postoperatively showed maintained improvement as follows: in 1954 group 30.7%, in 1955 group 64.7%, and in 1956 group 54.5%. The corresponding figures 400-700 days after mobilization were: 1954 group 27.5% and 1955 group 40%. Cases observed more than 700 days in 1954 and 1955 amount together only to 28, thus being too few for determining a percentage. The reliability of the figures decreases with the time elapsed, because the number of patients returning for check-up progressively diminishes despite all efforts. It is also difficult to evaluate the result in absent patients, since the cause of absence may differ widely.

We also made an attempt to check the maintenance of hearing gain in relation to the different levels achieved. The cases of Groups I-III are again classified by year of operation and length of observation period (Table 6).

This record shows that, when mobilization has resulted in restoration of hearing close to the bone conduction level (Group I), subsequent deterioration is infrequent and distinctly less frequent than in the less favorable groups. Furthermore, deterioration in this favorable group does not appear until about 300 days postoperatively. This table again indicates the favorable development from the first mobilization year to the

TABLE 6.—*Deterioration of Hearing to Preoperative Level Within Different Observation Periods*

Observation Time, Days	1954			1955			1956		
	I	II	III	I	II	III	I	II	III
-100	—	3	8	—	5	13	—	4	9
100-200	—	3	3	—	1	2	—	5	4
200-300	—	3	1	1	—	—	—	2	—
300-400	2	4	—	1	4	—	—	—	—
400-500	—	—	—	1	1	—			
500-600	—	—	—	—	—	—			
600-700	—	1	—						
700-	3	—	—						
Total	5	14	12	3	11	15	—	11	13
	12	29	18	21	29	22	23	64	32

third. In the last row are recorded the whole number of the primarily observed improvements in the different groups. These figures are higher than the total of observed patients because they include the cases with maintained improvement and those not obtained for control. The difference, however, distinctly increases in favor of the year 1956.

It is known that in most cases of fenestration a postoperative deterioration of hearing, when occurring, generally appears within the first six months. Our follow-up after mobilization does not show this regularity. Although deterioration in the majority of cases appears approximately within the first 400 postoperative days, there are many sporadic cases in which the patient loses his improvement later. Looking at Table 6, one does not find any regularity there.

Mobilization Methods Used

As was stated previously, it was mainly for two reasons that we tried to develop a new more satisfactory method than the original Rosen method: the poor visualization of the operative field and the comparatively numerous fractures. As for the first, our hope has been fulfilled by our own approach; as for the second, we must admit that the incidence of fractures has hardly diminished. However, as will be explained shortly, there are other factors which compensate for the unfavorable effects of a fracture. It may be added that, in the most recent period, we have experienced fractures less frequently, thanks to increasing experience with our technique.

The mobilization methods used in this material are (1) that of Rosen in its original form, (2) atticotomy and direct loosening of the footplate, published by me in 1955, (3) widening of the osseous meatus and direct loosening of the footplate, (4) the original Goodhill method, in which pressure is exerted against the lenticular process of the incus, and (5) a combination of the latter

TABLE 7.—*Incidence of Fractures*

Method	No. of Cases Observed	No. of Fractures	Per Cent Fractures	
Rosen	173	65	37.6	
Meurman, atticotomy + footplate mob.	40	17	42.5	32.4
Meurman, excavation of osseous meatus + footplate mob.	105	30	28.6	
Goodhill, simple pressure	34	4	11.7	
Goodhill + Rosen	22	5	22.7	
Myerson	1	1		
	375			

TABLE 8.—*Gain and Loss in Hearing*

Method	No. of Cases	Longest Observ. Time, Days	Loss 6 db. and More	Unchanged %	Improved			
					5-10 %	db. 11-20 %	db. >20 %	db. Total %
Rosen	168	1004	27.9	35.1	15.4	10	11.3	37
Meurman both m.	137	698	20.4	17.5	17.5	31.4	12.4	60
Goodhill	34	444	17.7	35.3	20.6	26.5		47
Goodhill + Rosen	22	460	22.7	31.8	13.6	13.6	18.2	45

and the Rosen method. Table 7 shows the incidence of fractures.

From this one might conclude, when not scrutinizing, that the method of Goodhill would be the most preferable. Yet the number of cases in which it was applied is at present very limited. Secondly, often it did not result in mobilizing the stapes, and it was necessary to resort to an additional procedure. It is understandable that fractures do not occur so easily when the pressure applied is divided approximately equally on both crura. On the other hand, the footplate, if strongly ossified, will not be separated by such a procedure. And if very much force is applied in this attempt, both crura can break, as happened in one case of ours. We have no experience of Goodhill's later method, in which vibrations of a dental burr handle are used to break the osseous bridges. Probably this method is more efficacious.

It looks as though my newest own method would be also less satisfactory. However, our experience of the last few months is more encouraging. In addition, even after a fracture has occurred, one can continue to break the bony bridges of the annular ligament and obtain a rather good improvement in hearing. Table 8 illustrates the gain and loss.

These figures showing the percentage of the cases operated on in each group were obtained by observing the longest follow-up checking; thus each case is taken into account only once. The times of observation vary in the first two groups rather similarly and so the figures are comparable. As the cases treated according to the Goodhill and the combined Goodhill-Rosen methods are much fewer and as also the observation times are shorter, a comparison with the methods longer used is perhaps not quite adequate. Yet the main features seem to emerge. Perhaps the most obvious differences are observed in the percentage of unchanged cases and the total number of improvements, both in favor of Meurman's method. In this respect the original Rosen method offers the poorest results. But there are factors which can explain this and at least partly restore the value of the last-mentioned method. The Rosen method was the first to be applied. At that time we had no previous experience. The mobility of the loosened stapes was perhaps in many cases not rightly evaluated. During the progress of time we learned that the excursions of the stapes must be rather extensive before convincingly indicating a real release. In some cases, at least in the first series, a fractured stapes was probably believed to be mobilized. This, of course, is not a full apology for the method, because it is due to poor visualization.

With our lancet knives we aim at breaking the bony bridges in the annular ligament. By a slow, even pressure one often succeeds in pushing the knife deep into the chink between the footplate and the window rim. The knife is next pulled out and pushed again close to the mentioned point. Since we recently substituted a saw-tooth-edged knife, for the even-edged knife, the freeing seems to have become easier in many instances. In those cases in which the footplate is osseously fixed along long stretches of the periphery the operation requires much time and perseverance for good results to be obtained.

The common experience of mobilization surgeons is that firmness of the stapedial crura varies considerably. It is really sur-

prising how thin and fragile they, or rather, one crus may sometimes be. In those cases the crus breaks whatever method is used. A fracture can occur at very different points: in the middle of a crus, at its junction with the footplate. Those are the most frequent points. But the capitulum can also be separated from the arch; the fracture occasionally goes across the most massive part of the stapes, the middle of the arch, often obliquely. Sometimes when we have tried to separate the footplate along the periphery between the crura, the plate has been broken.

During these manipulations a small quantity of perilymph has often oozed out. I don't think this is dangerous. In some cases a part of the footplate has broken out, resulting in an open hole. In most of these we have experienced no immediate harm, but, as for the eventual result, these cases are too fresh and too few to be evaluated. We intend to examine this point closer, possibly also experimentally later on. In one case we tried to close the open hole with a piece of acrylic. However, we intend next to use amnion as obturating membrane when available.

Although there may be some foundation in Howard House's opinion that different fixations must be separated differently, nevertheless at least at present the direct mobilizing of the footplate seems most reasonable.

Remobilization

In 34 cases in which the obtained improvement was lost or in which there was no improvement, the stapes was mobilized again. Preoperative audiograms in all these cases showed a favorable gap between the bone and air conduction. Twenty-three ears belonged to Group A, nine ears to Group B, and two ears to Group C. In one A case all records are lacking. After mobilization, further loss of hearing resulted in six ears, of which four belonged to Group A and two to Group B. There was no noticeable change in seven ears, i. e., two belonging to Group A, three to B, and two to C. The remaining 20 ears showed a distinct improvement. The follow-up time varied from 7 to 700 days, postoperatively. In Table 9 the cases are divided according to the result and duration of postoperative observation.

The mean improvement in the B cases varied only between 5 and 9 db. The one case which was followed for 700 postoperative days had a mean gain of 7 db. The highest mean improvement in the A cases was 23 db., which was observed 351 days after the mobilization. The records thus state that, of the A cases, distinctly more than half (16:22) were successfully treated. Slightly more than half of the B cases (5:9) were not helped by repeated mobilization, and in the two C cases hearing was not affected by the operation.

Most of the remobilizations (23) were done in 1956. In 1954 we remobilized only one, the B case which was examined 700 days after the mobilization and which had retained the improvement. Naturally the intervals between the first and second operation differed widely. The fixation of the footplate showed different degrees of firmness at the second operation. In some there was a very firm ossification, in others it was slight. At present it is difficult to account for this difference. Certainly a very good mobilization with a quite freely movable

TABLE 9.—*Extent and Duration of Improvement*

33 Cases Observed. Improved Cases 20.						
Observation time p. o. (days) Mean Improvement in db.	<100	100-200	200-300	300-400	700	Total
5-10	3A+1B	2A	1B	1B	1B	5A+4B
11-20	7A	1A				8A
21-30	2A			1A		3A
Total	12A+1B	3A	1B	1A+1B	1B	16A+4B

footplate does not always guarantee absence of recurrence. Some time ago an ear was operated on six months after the first mobilization, which had been a complete success: a distinct and free movement of fluid in the round window niche on pressing the stapes inward was observed. On the second occasion the stapes could be moved around neither the long nor the short axis. One had to push the lancet knife several times into the anterior periphery and twice into the posterior to get the footplate detached. No fracture occurred, and the phenomenon in the round window niche was again observed. The result at the operation table was highly satisfactory.

Complications

The question of fractures was discussed in dealing above with the technique. If the footplate is mobilized, one of the crura remaining attached to it, the outcome is good. When both crura are broken, fenestration is indicated. In three cases we tried to substitute a piece of Polystan for the crura but without success. When the capsule of the incudostapedial articulation is completely torn, a reposition of the lenticular process against the capitulum of the stapes is often successful. A partial laceration of the capsule does not result in impairment of hearing.

During separation of the "cuff" in the meatus externus and the drum from the sulcus, ruptures may occur in the soft parts of the meatus and in the drum. Tiny ruptures in the drum heal spontaneously. The wider ones must be repaired with full-thickness skin grafts from behind the auricle; these regularly become firmly attached. Small holes in the tympanic membrane may also be covered with Thiersch grafts.

Subsequent Fenestration

Up to the end of 1956 we had performed 45 fenestrations after unsuccessful mobilizations. The number was 4 in 1954, in the following year they increased to 31, and in 1956 the number was 10. Among these cases were such as had shown no improvement at mobilization, others with an immediate but too slight improvement, and cases in which the primary improvement was lost after intervals of varying length. Like most other mobilizing surgeons, we have not on the whole experienced unfavorable results. However, this group has not yet been subjected to a close study. Our opinion on this subsequent fenestration is positive.

There are surgeons who recommend an interval of some months before a subsequent fenestration. Since there are cases in which hearing may increase slowly, the primary peak being attained only after about one month, I suggest waiting for one month. Yet, if the fixation of the stapes is too rigid at the attempt of mobilization for a successful mobilization, a fenestration may be performed immediately in the same stage. A complete fracture, which makes impossible the reconstruction of the connection in the ossicular chain, is also an indication for fenestration. I have pointed out the possibility of immediate fenestration in my paper read at the West German Congress in 1955. In exceptional cases we have proceeded thus. With our approach to the operative field it is easy to continue the operation.

Experiences in Europe

The following account does not claim to be an exact statement of stapes mobilization in European countries. It may rather be considered a collection of random samples. However, an approximate conception of the present status of this operation can be obtained. I have received reports from 26 colleagues in different countries, but there are surely a great many otologists, not mentioned here, who have begun to practice this operation. I apologize for omissions in advance. The reports show that the new method is viewed with doubt here and there. Several prominent aural surgeons adhere to fenestration. They assert that results by fenestration are so good that a mobilization of the stapes in most cases seems unnecessary. Among these are Arslan (Padua) and

TABLE 10.—*Some Data on Mobilization Communicated by European Otologists*

Author	No. of Mobilizations	Technique	Results
Lennart Holmgren, Stockholm	160	Cleavage of footplate + cutting of anterior crus	Distinct primary improvement in 80%; after one year decreased to 50%
Skoog, Stockholm	150 "mixed cases"	?	30%—35% very good improvement; 50%—60% improved
Zöllner, Freiburg	140	Heermann	Primary positive results 70%—80%
Cawthorne, London	110	Direct loosening of footplate	25% very good, 20% less improvement, 55% very little or no improvement, 0% worse
Aubry, Paris	About 100	?	Acceptable results in over 50%; in only 10 cases deterioration
Fleischer, Leipzig	65	First Heermann, then omitted for Rosen	Very good 16 cases, good 17, satisf. 6; unsatisf. 9, no change 15, worse 2.
Jacobi, Clinic, Eckert-Möbius, Halle	62	Rosen 42 cases; Heermann 16 cases	Improved 30; no change 32
Hamberger, Gothenburg	57	Rosen	Good preliminary results in 30%
Andersen, Aarhus	54	Rosen ? 2 cases crurotomy	Improved 24 cases; maintenance in 20%
Herberts, Uppsala	51	Direct loosening of footplate	1/3 of cases 30 db. level, 1/4, moderate improvement; 1/3 no improvement, 4 cases worse
Opheim, Oslo	45	Rosen	In 4 cases improvement, in others passing improvement 2/3 successful
Sirala, Turku	30	Cleavage of footplate and loosening	
Freckner, Stockholm	24	Rosen ?	Successful 50%+ improved 25%
Messerklinger, Graz (Clinic Hofer)	15	1 Rosen 14 Heermann	10 improved, 4 no improvement
Riskaer, Copenhagen	9	Rosen	6 improved by 11-39 db.
Zangemeister, Hamburg	No data	Combined direct and indirect, also Fowler	In beginning good results in 40%; when old cases excluded, improved 90%-95%, recurrences 10%
Simson Hall, Edinburgh	—	First: "direct pressure," thereafter "removing of lenticular process, head, crura, eventually boring footplate according to failure or success in each stage"	Over-all success 44%; Group 2 slightly over 50%, Group 3 or 4 drops to 30%.
Schlander, Vienna (Dworacek)	—	Footplate loosening with needle or chisel	Positive results in 3/4 within 2 months; 1/5 of these back to preop. threshold; average improvement 24 db.
Jongkees, Amsterdam	—	?	Impression: good results in 1/3
Rollin, Hamburg	Occasional cases, if necessary immediate fenestration		

Escher (Bern). Eckert-Möbius (Halle) also takes a doubtful attitude, although Jacobi in his clinic has already mobilized 62 ears.

Some aural surgeons—Kindler, Mittermaier, Rüedi, Steurer, and Lœgaard—have begun with mobilizations but consider it too early to express their opinion before collecting a greater number of cases. Table 10 presents some illustrative data.

A great variety of techniques have been used. There are only a few who still adhere to the original Rosen method. Opheim states that he intends to change the technique, evidently owing to the poor results with the original Rosen. The more surprising is Fleischer's information that he has left Heermann's method in favor of Rosen's. He does not say whether his Rosen technique is the original or the newer one. Heermann, whose method seems to have much support in Germany, works the ossified annular ligament with tiny chisels. On the whole, we can state that the "direct method" has gathered many supporters. Also the Fowler method has found its way to European clinics.

It is difficult to get more definite information about the approach used by different surgeons. There are some who stress that they do not use any widening incisions in the meatus: Holmgren and Schlander. Most surgeons, however, remove bone from the upper posterior limbus. As far as can be concluded from the short reports, the microscope is commonly used and work is done sometimes even with 16 times magnification. For removal of bone curettes often seem to be satisfactory, but burrs are perhaps used by the majority.

The otologists performing mobilization do not restrict the indications to certain cate-

gories. It is remarkable that such a well-known fenestration operator as Simson Hall does not perform a fenestration before a trying to mobilize the stapes. Schandler expresses the opinion that cases with poor bone conduction are also suitable for a trial. Several surgeons follow the rule that mobilization should always be tried first: Lennart Holmgren, Zangemeister, Zöllner, Frenckner, Jongkees and Riskaer. Many have had good results with fenestration after an unsuccessful mobilization.

The present short survey has shown that numerous European aural surgeons take a lively interest in mobilization. On an average their experience is still short but is increasing rapidly. The impression is gained that numerous promobilization otologists are perhaps too optimistic in their conclusions, which is certainly due to their limited experience. Another group is cautious; they do not wish to express any definite opinion; they want to continue collecting results based on an increasing number of mobilizations. Lastly, there are those who have had a definite success with fenestration and a priori think that mobilization cannot compete with fenestration. We must admit that this view has some foundation when we consider the percentage of improved, reported on the basis of extensive series studied.

Comment

If we want to manipulate the stapes more than exert a pull on its neck, a good exposure of the field of operation is required. This is a prerequisite for "direct mobilization," i. e., mobilization of the footplate. It is also the requirement for a reliable control of work performed. Working through an ear speculum does not provide a wide enough field. We therefore prefer to make an incision in front of the crus helicis and use a retractor. A further advantage is that bimanual manipulation is possible. The operative cavity, moreover, is rendered larger by separating the soft parts from the meatal walls in the vicinity of the outer meatal orifice. Removal of the bony limbus in its posterosuperior periphery with curettes does not, in our opinion, give a sufficient visual area, at least not for control. The bone in this portion of the wall is compact and hard. With a biting burr it is possible to remove a sufficient amount. When approaching the exit of the chorda, it is advisable to exchange the cutting burr for a polishing burr in order to avoid a lesion.

At present most aural surgeons prefer the "direct loosening." If fixation is partial, a pull on the neck or pressure on the lenticular process will suffice. But pulling should be done with utmost caution, and the force applied must not be strong. It is possible that Goodhill's method of loosening by vibrations will bring additional success, but it will scarcely help when ossification of the ligament involves an extensive stretch of the periphery. We once tried vibration as proposed by Myerson. It resulted in luxation of the lenticular process and fracture of both crura. Freeing of the footplate offers a valuable advantage because, even in cases in which one crus breaks, the other crus is still capable of transmitting sound vibrations to the movable footplate. In our material many such cases with fracture showed a good improvement. We never intentionally fractured a crus or footplate as Fowler and Altmann do. But several times we experienced fracturing of the footplate, associated, nevertheless, with a good primary improvement. Without personal experience of Heermann's technique, I cannot judge about its pros and cons. Theoretically it ought to be equally as suitable as other methods. When working with needle-pointed instruments as Rosen does, and the lancet-pointed instruments devised by us, we found no great difference. However, it is probable that breaking of more extensive foci will succeed more easily with our instruments, and especially the new model with a toothed edge is still more efficient.

I think that the present material of 379 stapes mobilizations, although not as large as, for instance, the series of House and of Scheer—800 and 500 cases respectively—has yielded valuable observations which may

serve as a guide in the future. We have tried to consider it from several points of view, and the results, as far as we can judge, elucidate several problems. With respect to methods of mobilization our material is not completely homogeneous, but this drawback naturally affects other large series also. In the course of time experience increases and causes changes in the technique. Among valuable series collected in Europe, those of Lennart Holmgren, Skoog, and Cawthorne are to be mentioned in first place. Division of the cases into the groups A-C, as in the case of fenestration, shows that the best results are obtained in A cases. Good results are obtained also in B cases but less frequently. C cases show both qualitatively and quantitatively the poorest results.

The threshold level of 0-15 db., which is hardly ever achieved by fenestration, was present in 6% in the group of A cases. The level of 20-30 db. was obtained in 39% of A cases and in 22% of B cases, but in the C group only in 8.7%. In the whole material these good results represent 25%, but in Group A 45%. Cawthorne obtained "very good" results in 25% and Skoog in 30%-35%. These results are thus concordant. However, if our mobilizations in the year 1956 only are considered, the percentage of cases reaching above 30 db. level rises to 54.

A comparison of the different methods used on our patients is distinctly in favor of the "direct method" (i. e., loosening according to Meurman [Tables 3 and 8]). It must be admitted that the number of cases in the groups treated according to the Goodhill pressure method and the combined Goodhill-Rosen method is considerably smaller. Yet a difference as high as 13% is likely to be significant. As pointed out above, the results with this direct method proved to be even still more successful in 1957.

Summary

From April, 1954, to the end of the year 1956, a total of 379 mobilizations of the stapes for otosclerosis were performed by four surgeons: Y. Meurman, 165 cases; O. H. Meurman, 169 cases; E. Vaheri, 40 cases, and Samuel Rosen, 5 cases. The technique used was the original Rosen method in 173 cases; mobilization of the footplate after exposure of the attic with removal of the bridge or after enlarging the bony meatus posterosuperiorly (both devised by Y. Meurman), altogether 145 cases; mobilization by simple pressure on the lenticular process according to Goodhill, 34 cases, and the combined method of Goodhill and Rosen, 22 cases. In addition, one patient was operated on by the method proposed by Myerson.

The time of follow-up varied from less than 100 days postoperatively to more than 700 days, the maximum being 1004 days.

Before mobilization the hearing of speech and whisper was determined, and a pure-tone audiogram, speech audiogram, and Békésy audiogram were taken. In the postoperative course these examinations were usually repeated as follows: at discharge, i. e., five to nine days after operation, after an interval of about one month, three months, six months, one year, two years, and over two years. Owing to different circumstances these periods could not be strictly adhered to. Therefore it was easier to use 100-day, 200-day etc., observation times. In this survey chiefly only the pure-tone audiograms are considered.

The material was studied with respect to improvement and further loss in the different follow-up groups, the nature of the hearing loss (Shambaugh's groups A, B, C), the methods of mobilization used, and the relation between bone and air conduction. An account of remobilizations is given. Experiences elsewhere in Europe are briefly reviewed. The results are discussed from several viewpoints.

When the primary improvement is considered, the number of improved cases rose from 32% in 1954 to 72% in 1956. Thus the over-all proportion of these is 45%. The best results were obtained in 1956, chiefly owing to the method of footplate mobilization.

In studying the changes in decibel level, it was found that in a total of 15 cases air conduction had risen up to 0-15 db. level. This occurred only in the A group and represented about 6% of the whole group. In addition 39.3% of this group had attained the 20-30 db. level. In only 27.5% of the A group was no improvement obtained. In the B group the 0-15 db. level was not reached at all. The level 20-30 db. was reached by 21.2% of the B cases and by only about 9% of the C cases.

A comparison of postoperative air conduction and preoperative bone conduction showed similar results to those found when studying air conduction alone. The material was divided into groups I-IV according to the size of gap between air conduction and bone conduction, as follows: Group I, loss of AC 0-10 db. greater than BC; Group II, gap 15-20 db.; Group III, gap 25 db. and more. In three groups the gap had diminished; in Group IV there was no change or the gap had increased. Group I consisted of 56 cases, 14.7%; Group II of 122 cases, 32%. In this latter group the percentage in 1956 was 45%, whereas in 1955 it was only 21.3%. Group III represented 19% of the cases and Group IV (no positive result) 34%. It is evident that the rise of the air-conduction level and the decrease of the gap between the air and bone conduction are directly related.

Table 6 shows the cases with deterioration of hearing to preoperative level in Groups I-III and the relevant time. In the most favorable group (I) the improvement was mostly maintained. In the few cases in which deterioration appeared it occurred distinctly later than in the less favorable Groups II and III, at the earliest between 200 and 400 postoperative days.

In 34 cases in which the improvement was lost or in which no postoperative positive result appeared, a remobilization was performed. Of these cases 20 improved again. An improvement of 21-30 db. was obtained only in A cases. The B cases did not reach more than 5-10 db. improvement. It was interesting to notice that, even in half a year fairly rigid refixation of the stapes has occurred in some ears.

Fenestration at intervals of varying lengths was performed in 45 cases after mobilization with no or poor improvement. These cases have not yet been subjected to a close study. However, we are in favor of fenestration when the audiograms show suitable conditions. An interval of at least one month is suggested. If, at the attempt of mobilization, both crura are broken or if the footplate is too fixed to permit a mobilization, fenestration can follow in the same stage. The approach which I have devised is suitable also for fenestration.

A short survey with random examples of mobilizations elsewhere in Europe is presented. The aural surgeons who have performed a greater number of mobilizations have obtained results which, expressed in percentages, do not differ much from ours.

Conclusions

A prerequisite for a successful stapes mobilization is free exposure of the operative field, including the footplate. Sufficiently high magnification, obtainable only with a microscope, is necessary for evaluation of the movements of a mobilized stapes and for verifying occasional fractures of the stapes. Mobilization is not adequate until the excursions of the stapes obtained by gentle probing are fairly extensive.

When the stapes is rigidly fixed, only a direct attack on the ossified annular ligament will ensure mobilization. Direct loosening of the footplate is in principle the only proper method since there are no signs from which the firmness of the crura can be judged. In these manipulations utmost caution must be observed and ample time reserved. Yet in exceptional cases with very firm and extensive fixation, mobilization does not succeed. When direct loosening of the footplate was resorted to, good primary results reached 60% and more. In the group with a good primary result, refixation of the stapes occurs infrequently and later than in less favorable groups.

Remobilization of the postoperatively fixed stapes succeeds in about two-thirds of the cases. In cases with a negative result, fenestration is indicated if the gap between air conduction and bone conduction has remained favorable.

Mobilization of the stapes should always be tried before fenestration. Advanced age is no contraindication. As mobilization is not entirely devoid of danger, the matter must be carefully considered if the other ear is deaf.

Fredrikinkatu 20A.

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Audiology Section

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Experiences with Transossicular Mobilization of the Stapes

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This is a further report on a method of mobilizing the stapes for the improvement of hearing in otosclerosis which does not require an incision and opening into the middle ear cavity. It has proved successful in 58% of selected cases.

Recorded attempts to improve hearing date back to the works of Celsus.[2] It can be said that surgical measures to overcome deafness began in 1801, when Sir Astley Cooper[3] advocated perforating the ear drum membrane for deafness owing to obstruction of the Eustachian tube. He reported the results in 20 cases. Thereafter for many years the tympanic membranes were opened or removed in the hope of improving hearing. Subsequently, the ossicles, one or all, were removed. In 1876, Kessel[6] attempted to mobilize the fixed stapes footplate. His ideas were followed by many others; notable among them were Miot,[8] Blake,[1] and Jack.[5]

Probably because of the high percentage of failures, the operation for mobilizing the stapes for otosclerosis was abandoned at the beginning of this century. Later, attention was paid to the establishment of a substitute oval window by Holmgren,[4] Sourdille,[11] and Lempert.[7] Lempert should be given credit for establishing the value of the fenestration procedure. Recently Rosen[10] directed attention to the stapes and its mobilization. His results and those of others have stimulated much interest in this work.

All the operations for stapes mobilization require an incision, the production of a flap, and entry into the middle ear cavity. I have been using a procedure which makes these methods unnecessary. It was found that vibrations which originate at the short process of the malleus and are transmitted through the ossicular chain to the footplate of the stapes, will mobilize this structure and improve hearing in as many as 58% of selected cases. It can be stated with assurance that the results of the no-incision, transossicular, vibratory mobilization of the stapes equal those obtained by the open operation.

I have performed the transossicular attack upon the fixed stapedial footplate by vibrations originating at the short process of the malleus on 67 ears in 53 patients. Both ears were done in 14 patients. The ages varied from 16 to 78 years. In 40 of the 67 the bone conduction threshold was 10 db. or better. Twenty-eight of the forty improved from an average air conduction level of 35 to 45 db. to a good normal threshold of hearing. It can therefore be concluded that one may expect improvement in as high as 70% of cases if they are specially selected. Of the remaining 27 cases, 11 benefited in varying degrees. It is significant that the improvement was not as impressive in those patients whose bone conduction level was lower than 10 db. and

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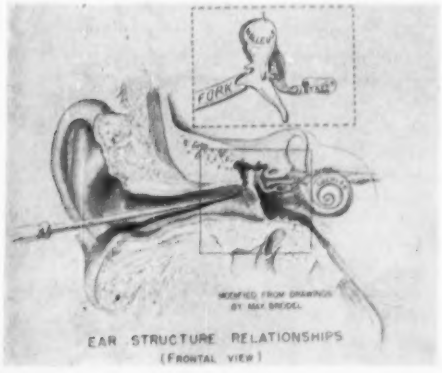
as low as 30 db. This is in accord with the experiences of others.

The technique of transossicular vibratory mobilization of the stapes has been previously described.[9] Anesthesia is obtained by a single injection of procaine solution 1%, with 12 minims (0.75 cc.) of epinephrine hydrochloride, 1:1000 to the ounce (30 cc.). The injection is simplified by the use of a 26-gauge needle, 2 in. long, attached to a ringed 2 cc. syringe. The flat, or oblique, end of the needle point is inserted into the skin at the point of juncture of the cartilaginous and osseous canals. The injection is usually accomplished at the first attempt. Three-tenths to five-tenths of a cubic centimeter of solution is sufficient to produce anesthesia. It is important to inject the anesthetic solution at the first attempt. Each attempt adds trauma; so there would be additional bleeding to handicap the surgeon. When a perforation of the tympanic cavity exists, some of the fluid leaks into the middle ear cavity and is drained off into the pharynx by way of the Eustachian tube.

A forked instrument, previously described, is placed upon the short process of the malleus and kept there. Although there is a variation in the size and contour of the short process, the same fork is effective in all cases (Fig. 1). With the fork in position, an assistant brings a revolving flattened rod in contact with its shaft. The rod, which is set in a dental handpiece, is

Fig. 1.—Forked instrument in position at short process of malleus.



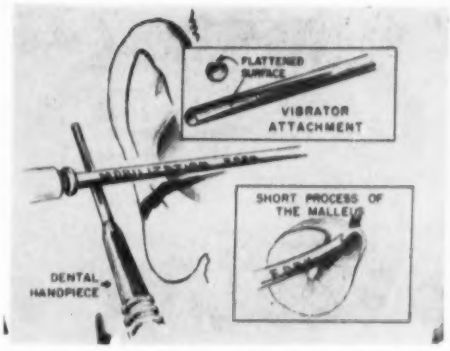


Fig. 2.—Rod flattened 0.030 in. in contact with shaft of forked instrument.

flattened 0.030 and 0.035 in. from its original diameter of 0.093 or $\frac{3}{32}$ in. These have been found to be the best degree of flattening for the desired amplitude and force of vibrations. When pain is experienced by the patient, it indicates that the maximum intensity of vibration has been reached. The number of revolutions per minute, which is 9000, is not important; the degree of flattening is. The revolving rod is controlled by means of a foot switch (Fig. 2).

In most of the cases, the forked instrument causes some contusion of the drum membrane in the region of the short process. In others, there is slight or no evidence that anything has been done. Despite the contusion of the tissues about the short process, immediate improvement in hearing

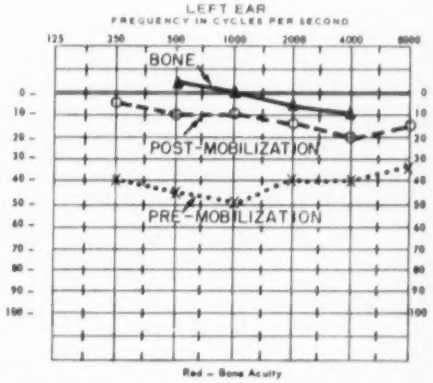


Fig. 3.—Hearing level before and after transossicular stapes mobilization in woman, aged 31.

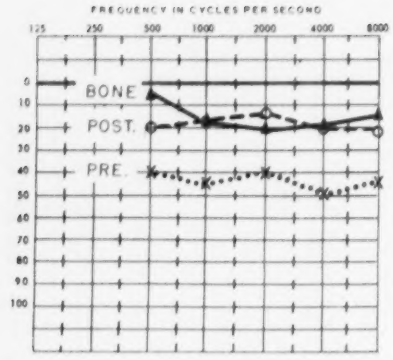


Fig. 4.—Hearing level in man, aged 47, before and after transossicular stapes mobilization.

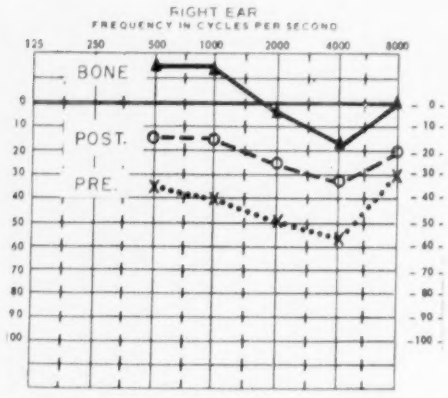


Fig. 5.—Audiogram of woman, aged 58, showing hearing level before and after transossicular stapes mobilization.

is registered in practically all successful cases. There were two exceptions in which improvement occurred some days later. One of these did not show improvement until 24 days after transossicular mobilization was attempted. At this time the patient's hearing suddenly improved, and her tinnitus disappeared. In the second patient, improvement of hearing occurred on the 14th postoperative day. Tinnitus was eliminated in approximately 50% of the successful cases.

Five cases in which the stapes could not be mobilized by the procedure were subjected to a modified Rosen exposure. Manipulation at the footplate resulted in improvement in two of the five cases.

The advantages of transossicular mobilization of the stapes can be listed as follows:

1. It carries no risk. There is no incision, no flap, no exposure of the middle ear cavity. It is a simple, uncomplicated procedure.

2. It requires less time; both sides can be done at the same session if desired.

3. It can be performed under general anesthesia if necessary or advisable.

4. It does not require a large number of instruments and elaborate equipment or technique.

5. Perforations do not occur; suppuration does not occur.

6. There is no postoperative displacement of the tympanic membrane.

7. There is no injury to vital middle ear structures.

8. There is no injury to inner ear structures, with total loss of hearing.

9. The procedure can be repeated with greater ease and no risk.

10. It can be performed when the open operation has proved unsuccessful.

11. The open operation and the fenestration operation are still available if a good result is not obtained.

None of the complications usually listed can occur.

The cases reported in this paper were done within a 10-month period. Six of the

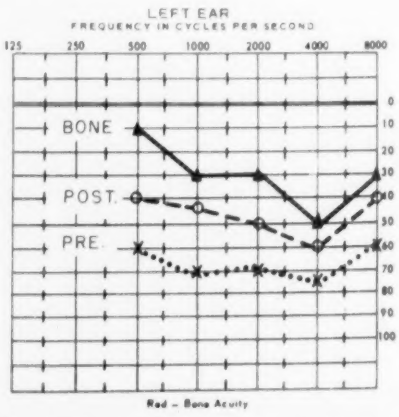


Fig. 6.—Hearing level in woman, aged 32, before and after transossicular stapes mobilization.

ears in which hearing was improved lost all or part of their improvement. Five of these had a bone conduction level of 20 to 30 db. The bone conduction level and the related air conduction level appear to be the best criteria for the results to be expected.

Conclusions

In 67 cases transossicular mobilization of the stapes was performed by a simple technique in which no complications or disadvantages were encountered. In specially selected cases, the successes may reach as high as 70%. The overall percentage of good results was 58.2. Refixation occurred in a small percentage of cases. There appears to be no difference between the results obtained from the transossicular stapes mobilization and those obtained with the open middle ear procedures.

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Movements of the Eardrum Following Intra-Aural Muscle Reflexes

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In recent years there has been a revival of interest in the reflectory contractions of the tympanic muscles since the acoustic reflexes of these muscles were proved to be of diagnostic value in various diseases.

Until the beginning of this century extensive research was devoted to the function of these muscles, mostly based on direct observations in animal experiments, using acoustic stimuli or irritation of the fifth and seventh cranial nerves. Summarizing this work it may be stated that musculus stapedius is innervated by the facial nerve and musculus tensor tympani by the trigeminus. During contractions the stapedius muscle pulls the drum outward, while the tensor muscle pulls it medially. Contractions of both muscles are elicited by sounds of a certain intensity via the cochlea and the acoustic pathways, the reflex arc not going above the brain stem. Contractions serve the purpose of protecting the cochlea against intense sound pressures.

Historical landmarks are Hensen's (1878) and Kato's (1913) demonstration of the tensor and stapedius reflexes, respectively, as well as the brilliant work of Wever and Vernon (1955) measuring the maximal strength and the reflex thresholds of both muscles.

It must be stressed that these results were all obtained from animal experiments. Fundamental knowledge of these muscles in human beings is presented in the work by Metz (1946) concerning the impedance method. In this method the physical characteristics of the tympanic membrane are evaluated by the ability to absorb and reflect sound, and also to change the phase of a note. Measurements are made with a so-called impedance bridge, consisting of two symmetrical metal tubes, into which a 768 cps test tone is emitted by a centrally situated telephone diaphragm. The end of one tube is closed by a variable resistance of comparison, which consists of a thin felt plate and metal piston, while the other tube is introduced airtight into the ear to be examined. The sound from both tubes bypasses the emitting membrane through a collateral tube. By auscultating this tube it is possible by means of the variable impedance to establish a state of balance in which the test tone is not heard, because tones from each side meet in exactly opposite phases to eliminate one another. When the mechanical status of the drum is altered, as happens during contractions of the tympanic muscles, the balance is disturbed, and the test tone reappears. Given the instrument, it is easy to use. Reports have appeared on the value of this method in the regional diagnosis in Bell's palsy (Jepsen, 1955), in recruitment determinations (Metz, 1952; Kristensen and Jepsen, 1952; Thomsen, 1955), and as an objective hearing test in malingering patients (Jepsen, 1953; Thomsen, 1955).

From these experiments doubt has arisen as to the function of the tensor muscle. In some patients with Bell's palsy the acoustic muscle reflex disappears temporarily, presumably as an expression of concomitant paralysis of the stapedius muscle. However, in patients with paralysis of the

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trigeminus, and consequently with paralysis of the tensor muscle, no such change could be found. These facts seem to be consistent with the theory that the stapedius muscle exclusively is responsible for the reflex recorded in the impedance method, and leave the function of the biggest of these muscles obscure. Jepsen (1955) concludes: "Strange to say, the problem whether or not acoustic reflex contractions of the tensor tympani occur in man has so far defied solution," and "the function of this muscle is obscure."

The confusion stems mainly from the anatomical position of these muscles. Direct observations can be made of the stapedius tendon through suitably situated perforations in the tympanic membrane. The knowledge gained through experiments on cases of this type still forms the firm basis for the theories concerning the function of the stapedius, even if finer but indirect methods have added considerably to this knowledge. It has never, even under extremely pathological conditions, been feasible to make direct observations of the tensor muscle, and no such basic knowledge exists concerning this muscle. Theoretically, contractions of the tensor muscle cause inward movements of the drum, and such movements might, although on an indirect basis, supply the missing evidence. Two methods are available for registering these movements, direct visual observations and the recording of corresponding pressure changes in the external ear canal.

In fact, Mangold (1913) reported such changes of pressure, and even made photographic recordings of small, three to four per second, inward movements by means of a simple manometer connected to the external ear canal, the whole system, including the meatus, being filled with water. Movements were seen in persons able to perform voluntary contractions of the tensor muscle. Despite several attempts, he succeeded in demonstrating reflectory movements in only one person, and here special conditions were thought to be involved. Cemach (1920) found this method unusable.

Direct visual observations of inward movements of the drum were made by Ostmann (1898). Strong disagreements regarding such movements prevailed during the following years. Waar (1923) and Lüscher (1929), using adequate ear microscopes, finally disproved any such movements. In recent years the immobility of the tympanic membrane during contractions of the intra-aural muscles has been a virtual dogma.

Nevertheless, possible movements in the inward direction of the tympanic membrane appear to afford the only means of proving a function of the tensor muscle. In a renewed attempt to demonstrate such movements, it was felt that registration of pressure changes in the external meatus would be most profitable, since only a few and inconsistent reports about this method are available, while direct visual observations made with modern equipment all have been disappointing.

Method

The prerequisite for recording changes of volume or pressure is an absolutely airtight closure of the external meatus. A serviceable method seems to be application of an inflatable rubber cuff around the earpiece connecting the meatus to the manometer. This method was described for other purposes by Wojatschek (1908) and used by Metz in his new model of the impedance bridge. Accordingly, an earpiece was constructed (Fig. 1) consisting of a double metal tube, with a 1.8 mm. tube placed inside a 2.7 mm. tube, both being soldered together at each end. One centimeter from one end of this double tube a smaller gauge side tube is attached to connect a rubber bag with the narrow space between the tubes. Four millimeters from the opposite end of the double tube another hole is made in the outer tube, and a small preformed latex rubber cuff is tied over this end. So a direct connection is established between the

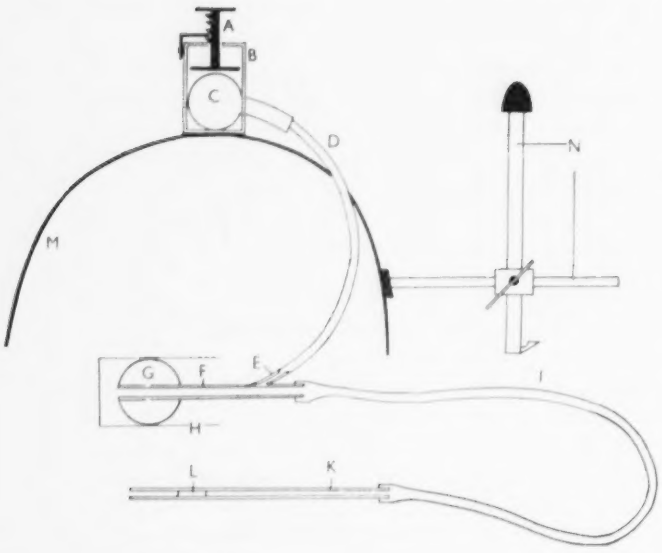

Fig. 1.—Diagram of the equipment: *A*, plunger; *B*, metal housing; *C*, compressible rubber bag; *D*, rubber tube; *E*, metal side tube; *F*, earpiece; *G*, latex rubber cuff; *H*, external ear canal; *I*, rubber tube; *K*, glass-tube gauge; *L*, fluid drop; *M*, flexible headband; *N*, adjustable obturator.

latex cuff and the mentioned rubber bag, which, placed in a metal housing, can be compressed by a plunger in steps to inflate the cuff. The plunger shaft is supplied with cogs so that it can be retained in the different positions. As seen in Figures 1 and 2, the metal housing is placed on a flexible headband for convenience. Some ear canals open outward in a conical fashion. Inserted into such ear canals this earpiece shows a tendency to expel itself when the cuff is inflated. To obviate this tendency an adjustable iron bar was fitted to the headband. A hook on one end inserted into the angle between the double tube and the smaller side tube proved adequate to keep the earpiece in place under all conditions.

Only small and weak movements were anticipated, so direct recordings of pressure were thought to be obsolete. Instead a small-caliber glass tube with a fluid drop was used. As adhesive powers in such a

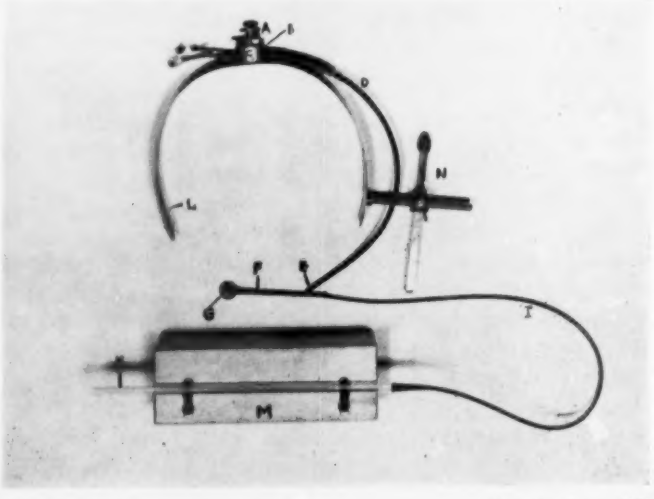

Fig. 2. — Equipment: *A*, plunger; *B*, compressible rubber bag; *C*, metal housing; *D*, rubber tube; *E*, metal side tube; *F*, earpiece; *G*, latex rubber cuff; *I*, rubber tube; *K*, glass-tube gauge; *L*, flexible headband; *M*, holder for glass tube; *N*, adjustable obturator.

capillary are considerable, the fluid had to be one of low surface tension. Alcohol, ether, and gasoline were all tried out and proved adequate. With the use of water no movements whatsoever of the drop could be seen, even under a high-power ear microscope.

Pilot tests showed it permissible to connect the earpiece to the glass-tube gauge by a small-caliber rubber tube. Thus small, unavoidable movements of the patient's head do not interfere with the observation of the glass tube, even if they should the actual pressure exerted on the fluid drop is reduced in proportion to the increased volume of air between this and the tympanic membrane.

The muscle reflexes were elicited from the opposite ear by Bárány's noise box or an audiometer.

Results

This is a preliminary report, and only general statements will be made. In nearly all normal ears a reflex movement of the fluid drop can be seen. If there have been previous episodes of otitis media, movements become more unpredictable, presumably because of fibrous fixation of the ossicles. If flaccid, atrophic areas on the drum are present, movements of the manubrium mallei may be followed by simultaneous movements in the opposite direction of this flaccid area. Therefore, as a result, there will be no change in the volume of the external ear canal, and consequently no movement of the fluid drop.

In many cases, however, even severe scarring of the drum does not preclude relatively large movements. Ordinarily movements are quite small. On an average the fluid drop travels 0.5-1 mm.; occasionally movements of 1 cm. and more have been recorded. As the caliber of the glass tube is 0.7 mm., the drum movements thus amount to a total displacement of the tympanic membrane of less than 1 cu. mm. This accounts in full for the unsuccessful attempts to visualize these movements by direct observation of the drum.

Comparison has been made with reflex thresholds obtained by the impedance method. This method usually is capable of proving reflexes at slightly lower intensities, especially when movements of the drum are small and approaching barely visible jerks. This result was to be expected. Muscle contractions gradually increase in intensity during the first 10-20 db. above threshold, thus movements become more abrupt and easier to observe. In the impedance method the stiffness of the conductive mechanism is measured. Patients have been encountered on whom a definite reflex could be recorded by this method while no movements of the drum were present. Presumably in these patients simultaneous contractions of both intra-aural muscles exactly counteract each other, so as a result only stiffness changes appear.

In the introductory comments the problem of the tensor muscle was especially mentioned. Preliminary tests show that in different patients movements in both the inward and the outward direction occur, with no difference in the reflex movement otherwise. This proves that, in some persons anyway, there is an acoustic tensor reflex equal to the stapedius reflex. In view of this fact some of the problems pertaining to cases with Bell's palsy and trigeminus paralysis seem even more confusing. Further research is in progress with the aim to solve these problems.

Summary

A method is presented by which drum movements can be recorded following reflectory contractions of the intra-aural muscles. The existence of an acoustic reflex of the musculus tensor tympani in the human being is established.

Aabrinken 205.

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Clinical Notes, New Instruments and Techniques

A Knife for Cutting the Stapedius Tendon

CAPT. MAURICE SCHIFF (MC) and CAPT. GERALD W. HURST (MC), U. S. N.

The opinions or assertions contained herein are the private ones of the authors and are not to be construed as official or reflecting the views of the Navy Department or the Naval Service at large.

During the operation for mobilization of the stapes, one encounters at times a fibrotic or atrophic stapedius tendon. Because of difficulty in severing this tendon with ease, the following instrument was devised.*

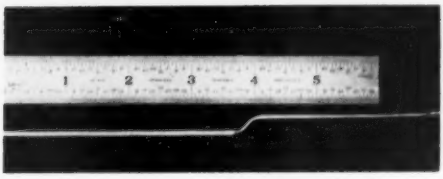


Fig. 1.—Instrument, profile view, with bayonet-type handle.

Accepted for publication March 19, 1957.

From the Otolaryngology Branch of the Eye, Ear, Nose, and Throat Service, U. S. Naval Hospital, Oakland, Calif.

* This instrument was devised by the authors and is manufactured by the O. Olson Surgical Instrument Company, Oakland, Calif.

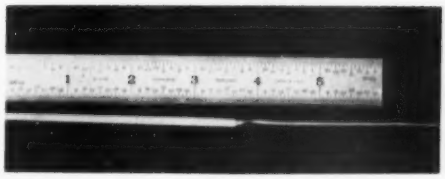


Fig. 2.—Instrument, front view, showing thinness of the blade.

It will be noted that in profile (Fig. 1) the handle is of bayonet type, permitting the fingers to be out of the visual axis (front view, Fig. 2). A small sickle contour to the knife blade permits the engaged tendon to move toward the sharpest portion of the blade. A slight up-and-down motion with minimal pressure permits easy cutting of the tendon and constant visualization of the knife-blade tip. The latter affords a safety factor in that one could see if the tip were approaching the facial nerve. An additional safety factor can be had by making the cutting stroke in the direction away from the facial nerve. The latter, unfortunately, usually is technically difficult because of exposure. It is to be noted that this tendon can be severed with considerably greater ease if it is cut before the fixed stapes is made mobile.

U. S. Naval Hospital, Oakland, Calif.

Otitis Media

GREYDON G. BOYD, M.D., New York

A case of secretory otitis media with implantation of a plastic tube into the middle ear is presented. The method used differs from that described by Armstrong,[1] as the tube is inserted under the drum and a skin flap adjacent to it, rather than through the drum. This method enables one to inspect the middle ear and should be less likely to result in a residual perforation and infection. The case history is of interest, because of the long duration of symptoms and the extended period of observation.

Accepted for publication June 14, 1957.

Case History

A boy, age 10 years, was first seen in October, 1954, with the complaint of tinnitus and hearing loss in the right ear. Symptoms had been present since the patient had mononucleosis and pneumonia at age 5. One attack of otitis media occurred prior to a tonsillectomy at age 4½. Hearing loss and tinnitus became worse with recurring attacks of upper respiratory infection and allergic rhinitis. He has been under an allergist's care for sensitivity to pollens, molds, and animal dander, and for slight asthma. The right ear remained blocked

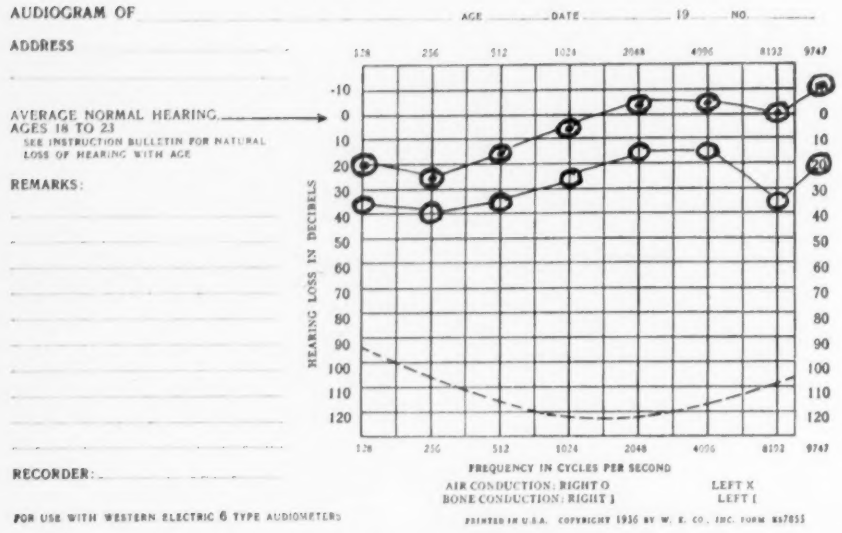


Fig. 1.—Audiogram on first visit, below; and following adenoidectomy and aspiration of the middle ear, above.

up, in spite of treatment, including the use of cortisone. He had an unpleasant diplacusis, making practice on his violin annoying. Headaches occurred from minor blows about the head.

When he was first seen, examination showed a thickened right ear drum with fullness anteriorly and a faint amber reflex. Polypoid changes of the right middle turbinate were present. Some lateral adenoid tissue and edema of the Eustachian orifices were noted. Inflation gave a moist sound. The hearing was as shown in Figure 1. On Nov. 5, 1954, a secondary adenoidectomy was done, and clear amber serous fluid was aspirated from the right middle ear. The hearing improved, as shown in Figure 1. Beginning Nov. 19, 1954, a course of radium applications was given to the Eustachian orifices. On April 1, 1955, he was hospitalized with an acute upper respiratory infection and

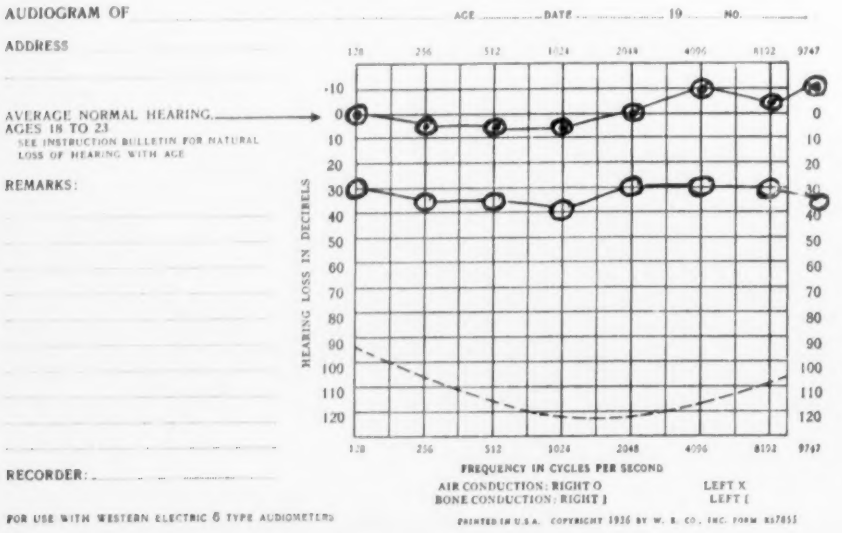


Fig. 2.—Audiogram before opening, below; and after opening of ear, above.

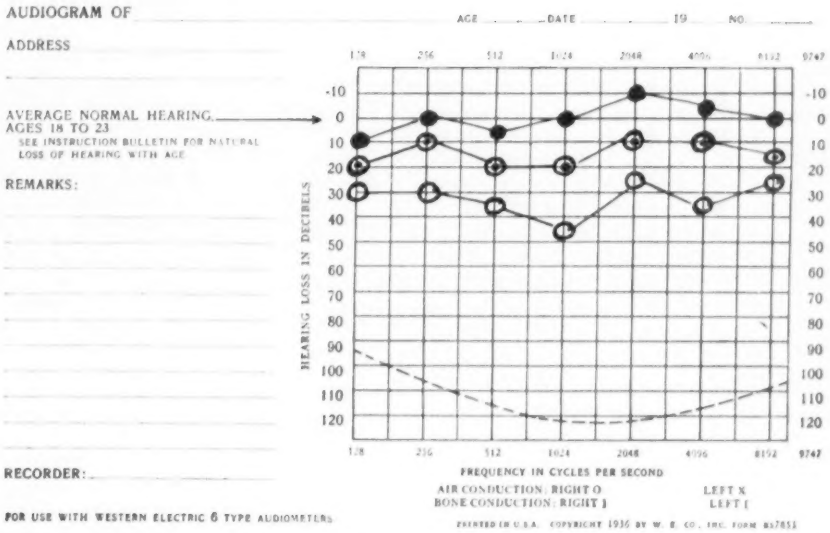


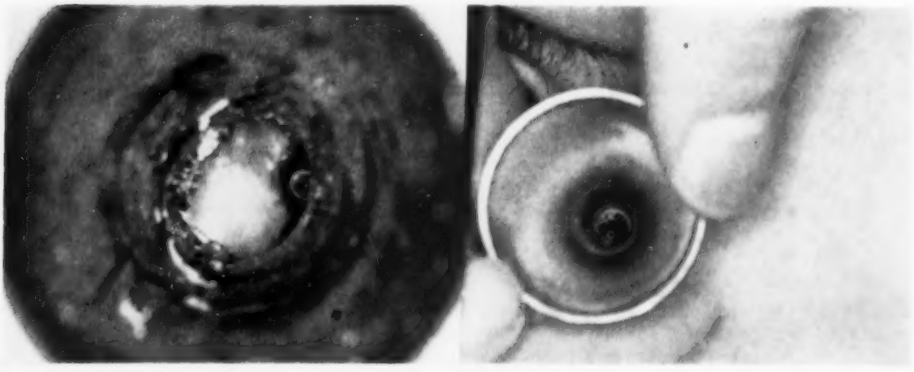
Fig. 3.—Audiogram before (open circles) and after (dotted circles) aspiration on Dec. 22, 1955; and on Feb. 17, 1956 (solid circles).

serous otitis media associated with vertigo. His hearing then is shown in Figure 2. The drum was retracted. A little amber fluid was aspirated, associated with an audible popping sound as the drum came away from the promontory. Hearing improved immediately (Fig. 2). Mastoid x-rays showed some cloudiness of the right mastoid cells. In July a similar episode occurred, with some drainage of sterile fluid from the ear. A mastoidectomy was considered by another physician who was treating him at that time. On Oct. 14, 1955, after a cold, the drum was found to be markedly retracted. An audible pop with hearing improvement occurred when a needle was inserted through the drum, but no fluid was obtained. Air could be made to enter the middle ear with inflation, but not well. The nasopharynx and Eustachia tube orifices were normal in appearance. On Dec. 22, 1955, hearing was as shown (Fig. 3), before and after aspiration, when a little amber fluid was obtained. The drum was markedly retracted against the promontory.

Procedure

It was decided to place a plastic tube in the middle ear, using the approach for mobilization of the stapes. This was done on Dec. 28, 1955, using local anesthesia. The incision was made from about 3 to 8 o'clock around the canal inferiorly and about 5 to 7 mm. external to the drum margin. The mucous membrane lining of the middle ear

Fig. 4.—Photographs of plastic tube in place.



was found to be glistening white, very thick and fibrotic. No fluid was present. The fibrotic mucous membrane was incised from 5 to 7 o'clock, but the drum could not be completely elevated anteriorly because of pain (the only discomfort during the procedure). The Eustachian tube was not visualized. A plastic tube 0.38 mm. inside diameter by 1.09 mm. outside diameter and ½ in. long was inserted at about 8 o'clock (Fig. 4). The drum and flap were replaced and covered by two layers of nylon. Cotton pellets moistened with saline were used for packing. The cotton was removed the following morning and the nylon one week later. The drum was then still retracted. Fifty-one days after operation the drum was only slightly retracted, white, and with a cone of light present. The tube was in place, and the skin flap healed tightly around it. The hearing was normal (Fig. 3). A severe upper respiratory infection was just subsiding at this time without effect on his ear. The tube was removed easily. Since removal there has been no recurrence of trouble. He is less nervous and has not experienced headaches or diplacusis, as previously.

Comment

The optimal length of time the plastic tube should remain in place for such a case is yet to be determined. There is no evidence of adverse tissue reaction, infection, or discomfort from the tube. The insertion of a plastic tube under a skin flap and under the periphery of the ear drum is offered as a possible treatment for secretory otitis media resistant to other forms of treatment.

135 E. 64th St. (21).

Addendum

Follow-up 18 months after operation: The drum is now moderately retracted. There does not seem to be any fluid present in the middle ear. The patient has no discomfort or diplacusis as formerly.

The hearing is shown to have receded somewhat from its best level.

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News and Comment

ANNOUNCEMENTS

Pan-Pacific Surgical Association.—The Seventh Congress of the Pan-Pacific Surgical Association will be held in Honolulu, Hawaii, Nov. 14-22, 1957. All members of the profession are cordially invited to attend and are urged to make arrangements as soon as possible if they wish to be assured of adequate facilities.

An outstanding scientific program by leading surgeons with sessions in all divisions of surgery and related fields promises to be of interest to all doctors.

Further information and brochures may be obtained by writing to Dr. F. J. Pinkerton, Director General of the Pan-Pacific Surgical Association, Room 230, Young Building, Honolulu, Hawaii.

Books

Industrial Deafness: Hearing Testing and Noise Measurement. By Joseph Sataloff, M.D., D.Sc. (Med.). Price, $8.00. Pp. 325. The Blakiston Company, division of McGraw-Hill Book Company, Inc., 330 West 42nd St., New York 36, 1957.

A text on industrial deafness has long been overdue on the American medical scene. This volume is an excellent presentation, which should be of great interest not only to otologists but also to industrial physicians, safety engineers, compensation and insurance executives, and others interested in the effects of noise upon man.

This has become a noisy world. The noise has shattered our equanimity and, to a certain extent, is shattering our ears.

Since it has been demonstrated both clinically and experimentally that acoustic trauma will destroy auditory function, it behooves every physician to concern himself seriously with the effects of noise on the human ear. In military life and industry, contact with high noise levels is on the constant increase. Noise now joins the list of significant etiologic agents in the causation of disease.

Industrial medicine, otology, and preventive medicine became aware of this problem acutely during World War II, when noise levels produced by new industrial and military devices reached seriously traumatic levels. Research into this field has progressed rapidly during the past decade.

The recent publication of "Industrial Deafness: Hearing Testing and Noise Measurement" by Dr. Joseph Sataloff, is a noteworthy and historically significant contribution to work in this field. Dr. Sataloff, who has made many contributions to otology and audiology, and has been a lecturer in the field of industrial deafness for a number of years, has thoughtfully and carefully brought forth a text which should be of great value to all people concerned with the effects of noise upon man.

There has been a great need for just such a volume which brings together in one book all of the pertinent information in this very new field of knowledge.

In order to bring authoritative information in such varied areas as acoustic physics, principles of noise measurement techniques and noise abatement design of audiometric test rooms, etc., the author has wisely enlisted the active contributions of four engineering specialists, Drs. Charles R. Williams, Robert Roop, Robert Goldman, and John A. Zapp, Jr.

He has also utilized some of the excellent material prepared by the Sub-Committee on Noise and Industry of the American Academy of Ophthalmology and Otolaryngology to illustrate methods of direct approach to workers in noise to expedite hearing conservation programs in industry.

The book includes such chapters as "Damage-Risk Criteria," "Ear-Protectors," and "Handicapping Effects of Deafness," as well as material on causes of deafness, auditory testing techniques, etc., etc.

The author urges caution in audiometric testing technique and points out possible errors in such techniques when used by inadequately trained industrial hygiene technicians and others.

This is an unusual first text on a new subject in that it is also a mature and sober evaluation of the entire field.

It should be on the desk of every industrial physician, otologist, safety engineer, and all those concerned with the medical, legal, and insurance aspects of the effects of noise upon man.

Oto-Rhino-Laryngology in Relation to Neurology. By Jacques Lemoyne. Oto-Rhino-Laryngologist to the Hospital of Paris. Price 200 francs (about $50). Paper bound, with 73 illustrations. Masson & Cie, 120 boulevard Saint-Germain, Paris 6e, 1956.

This manual is a correlation between otorhinolaryngology and neurology. Each section is presented clearly and comprehensively. Normal anatomy is correlated with neuroanatomy; then the pathologic conditions of each are presented with their influence and neurologic responses, and vice versa.

The first section deals with otology, which is subdivided in (1) the cochlea and (2) the labyrinth. In the former section, there is a discussion of normal hearing tests and their application; deafness is discussed, and also malingering and deaf-mutism. The vestibular apparatus is similarly discussed, e. g. anatomy, neuroanatomy, physiology, and the various vestibular tests with their significance. There is also a detailed discussion of various symptoms, and the relationship, direct or indirect, to neurologic pathology. Especial emphasis is placed on acute and chronic meningoencephalitis and cranial traumatism.

The second section deals with the nasal fossae and sinuses. Special consideration is given to olfaction, anosmia, frontal sinus symptoms, indeterminate headaches, visual disturbances, and traumatic sequelae.

The third section discusses the pharynx and larynx. Here, too, the various neurologic implications are greatly stressed.

This book is concisely presented and is recommended to both the otorhinolaryngologist and the neurologist.

A. M. A. Scientific Exhibits 1956. Sponsored by the Scientific Assembly American Medical Association. Price $10.00. Pp. 411, Cloth bound. Grune & Stratton, Inc., 381 Fourth Ave., New York 16, 1956.

This book is a compilation of all the scientific and some of the commercial exhibits shown at the 1956 meeting of the American Medical Association. The exhibits that received prizes or honorable mention have been photographed. Summaries have been presented of all other exhibits.

"A. M. A. Scientific Exhibits" presents an opportunity to review the various exhibits at one's leisure and to analyze the many new and interesting concepts of our present day problems in medicine, surgery, and allied branches.

The format is excellent, and the comprehensive table of contents permits the reader a ready reference to pertinent subjects, etc.

The book is recommended to the entire medical profession, and its publication should be repeated for each succeeding meeting of the American Medical Association.

BOOKS RECEIVED

Peristalsi ed antiperistalsi dell'esofago. By Dott. Giovanni Motta, Assistente Clinica Otorinolaringologica di Bologna. (Ricerche Sperimentali, con prefazione del Prof. A. Clementi, Direttore, Instituto di Fisiologia Umana Dell'Università di Catania). Price, not given. Pp. 93, including bibliography; illustrated by charts. Text in Italian. L. Cappelli, Via Farini 6 Bologna, 1956.

Liver, Biliary Tract and Pancreas. By Frank H. Netter, M.D. A Compilation of Paintings on the Normal and Pathological Anatomy of the Digestive System. Part III of Volume 3 of the Ciba Collection of Medical Illustrations. Price, $10.50. Pp. 156; 133 full-color plates by Frank Netter, M.D., with accompany text by authorities in their fields. Commissioned and published by CIBA Pharmaceutical Products, Inc., Summit, N. J., 1957.

* **Exposes annuels d'oto-rhino-laryngologie.** Publiés sous la direction de R. Maduro and J. Bouche, Collège des Hopitaux de Paris (Section d'Oto-Rhino-Laryngologie). Série 1956. Articles by various authors, in French. Price, 1600 fr. Pp. 266, with 32 illustrations. Masson et Cie, 120 Boulevard Saint-Germain, Paris 6e.

*Will be reviewed.

Directory of Otolaryngological Societies *

FOREIGN AND INTERNATIONAL

Canadian Otolaryngological Society
(Société Canadienne d'Otolaryngologie)

President: Dr. G. M. T. Hazen, 208 Canada Building, Saskatoon, Sask.
Secretary: Dr. G. A. Henry, 328 Medical Arts Building, Toronto.

Venezuela Otorhinolaryngology Society

President: Dr. Alfredo Celis Pérez.
Secretary: Dr. Jesús Miralles.

International Bronchoesophagological Society

President: Dr. Theodor Hünermann, Düsseldorf.
Secretary: Dr. Chevalier L. Jackson, 3401 N. Broad St., Philadelphia 40.

International College of Surgeons, Section of Ophthalmology and Otolaryngology

President: Dr. Henry M. Scheer, 522 W. End Ave., New York 24.
Secretary: Dr. Louis Savitt, 3402 W. Lawrence Ave., Chicago 25.
Place: Palmer House, Chicago. Time: Sept. 8-12, 1957.

International Congress of Audiology

General Secretary: Dr. H. C. Huizing, 182 Oostersingel, Groningen, Netherlands.
Place: Leyden, Netherlands.

International Course in Paedo-Audiology

General Secretary: Dr. H. C. Huizing, 182 Oostersingel, Groningen, Netherlands.
Place: Groningen, Netherlands.

Pan-American Association of Oto-Rhino-Laryngology and Broncho-Esophagology

President: Dr. José Gros, Havana, Cuba.
Secretary: Dr. Chevalier L. Jackson, 3401 N. Broad St., Philadelphia 40.
Meeting: Sixth Pan-American Congress of Oto-Rhino-Laryngology and Broncho-Esophagology.
Place: Brazil. Time: 1958.

Sixth International Congress of Otolaryngology

President: Dr. Arthur W. Proetz, 3720 Washington Blvd., St. Louis.
General Secretary: Dr. Paul H. Holinger, 700 N. Michigan Ave., Chicago 11.

NATIONAL

American Medical Association, Scientific Assembly, Section on Laryngology, Otology and Rhinology

Chairman: Dr. Gordon D. Hoople, 1100 E. Genesee St., Syracuse, N. Y.
Secretary: Dr. Hugh A. Kuhn, 112 Rimbach St., Hammond, Ind.

American Academy of Ophthalmology and Otolaryngology

President: Dr. Erling W. Hansen, 90 S. Ninth St., Minneapolis.
Executive Secretary-Treasurer: Dr. William L. Benedict, 100-1st Ave. Bldg., Rochester, Minn.

American Board of Otolaryngology

President: Dr. Frederick T. Hill, Professional Building, Waterville, Maine.
Secretary-Treasurer: Dr. Dean M. Lierle, University Hospitals, Iowa City.

* Secretaries of societies are requested to furnish the information necessary to keep this list up to date.

AMERICAN BRONCHO-ESOPHAGOLOGICAL ASSOCIATION

President: Dr. Clarence W. Engler, 2323 Prospect Ave., Cleveland.
Secretary: Dr. F. Johnson Putney, 1719 Rittenhouse Sq., Philadelphia 3.
Place: Fairmont Hotel, San Francisco. Time: May 19-20, 1958.
Place: The Homestead, Hot Springs, Va. Time: March 8-9, 1959.

AMERICAN LARYNGOLOGICAL ASSOCIATION

President: Dr. LeRoy A. Schall, 243 Charles St., Boston 14.
Secretary: Dr. Harry P. Schenck, 326 S. 19th St., Philadelphia 3.
Place: Statler Hotel, Washington, D. C. Time: May 3, 1957.

AMERICAN LARYNGOLOGICAL, RHINOLOGICAL AND OTOLOGICAL SOCIETY, INC.

President: Dr. Percy E. Ireland, 100 College St., Toronto, Canada.
Secretary: Dr. C. Stewart Nash, 700 Medical Arts Bldg., Rochester 7, N. Y.
Place: Mark Hopkins Hotel, San Francisco. Time: May 21-23, 1958.

AMERICAN RHINOLOGIC SOCIETY

President: Dr. Walter E. Loch, 9 Beechdale Rd., Baltimore 10.
Secretary: Dr. Robert M. Hansen, 1735 N. Wheeler Ave., Portland, Ore.
Annual Clinical Session: Illinois Masonic Hospital, Chicago, October, 1957.
Annual Meeting: Palmer House, Chicago, October, 1957.

SECTIONS:

Eastern.—Chairman: Dr. Joseph Sullivan, Toronto, Canada.
Southern.—Chairman: Dr. Mercer G. Lynch, New Orleans.
Middle.—Chairman: Dr. Paul M. Moore, Cleveland.
Western.—Chairman: Dr. Sigurd v. Christierson, San Francisco.

AMERICAN OTOLOGICAL SOCIETY, INC.

President: Dr. John R. Lindsay, 950 E. 59th St., Chicago 37.
Secretary-Treasurer: Dr. Dean M. Lierle, State University of Iowa, Iowa City.
Place: Fairmont Hotel, San Francisco. Time: May 17-18, 1958.
Place: The Homestead, Hot Springs, Va. Time: March 13-14, 1959.

AMERICAN OTORHINOLOGIC SOCIETY FOR THE ADVANCEMENT OF PLASTIC AND RECONSTRUCTIVE SURGERY, INC.

President: Dr. Joseph Gilbert.
Secretary: Dr. Louis Joel Feit, 66 Park Ave., New York 16.

AMERICAN SOCIETY OF FACIAL PLASTIC SURGERY

President: Dr. Irvin J. Fine, 505 New Brunswick Ave., Perth Amboy, N. J.
Secretary: Dr. Samuel M. Bloom, 123 E. 83rd St., New York 28.

AMERICAN SOCIETY OF OPHTHALMOLOGIC AND OTOLARYNGOLOGIC ALLERGY

President: Dr. Sam H. Sanders, 1089 Madison Ave., Memphis 3.
Secretary-Treasurer: Dr. Michael H. Barone, 468 Delaware Ave., Buffalo 2.
Place: Palmer House, Chicago. Time: October, 1957.

OTOSCLEROSIS STUDY GROUP

President: Dr. Joseph A. Sullivan, 174 St. George St., Toronto 5, Canada.
Secretary-Treasurer: Dr. Arthur L. Juers, 611 Brown Building, Louisville.
Place: Palmer House, Chicago. Time: Oct. 12, 1957.

SOCIETY OF MILITARY OTOLARYNGOLOGISTS

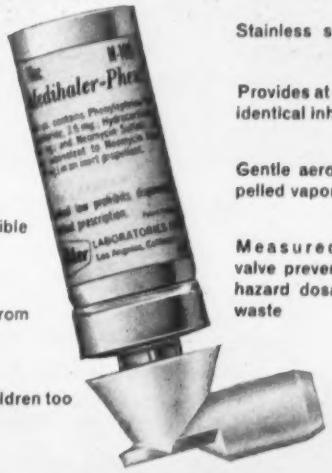
President: Col. Wendell A. Weller.
Secretary-Treasurer: Major Stanley H. Bear, M. C., 3810th USAF Hospital, Maxwell AFB, Ala.

In Head Colds

and allergic rhinitis, sinusitis, nasopharyngitis

Total Area Decongestion

Actual Vest-Pocket Size



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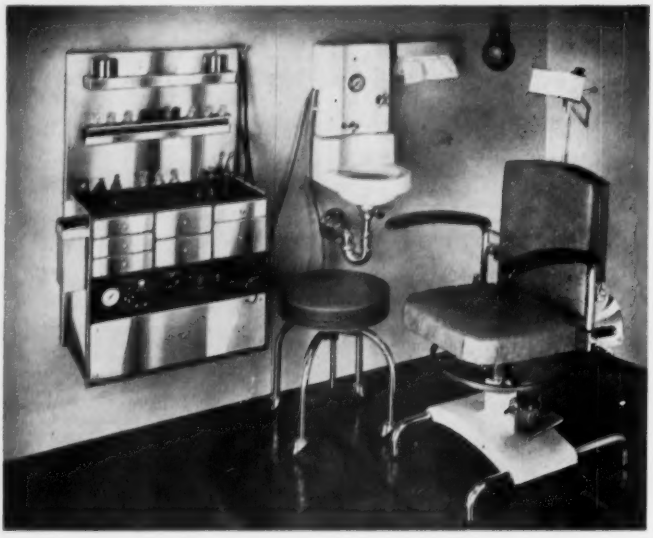

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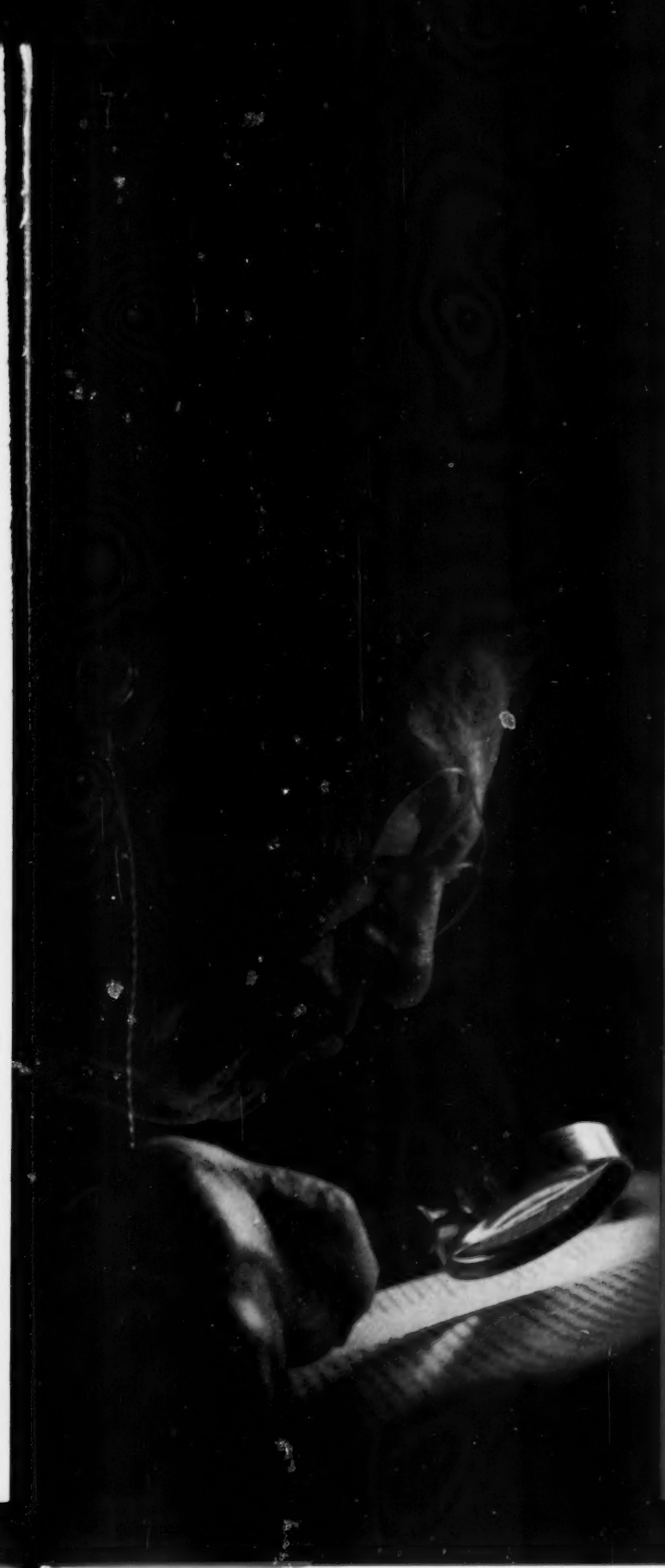

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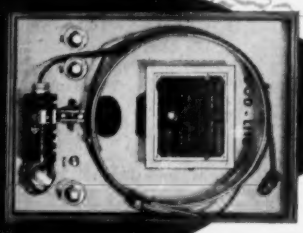

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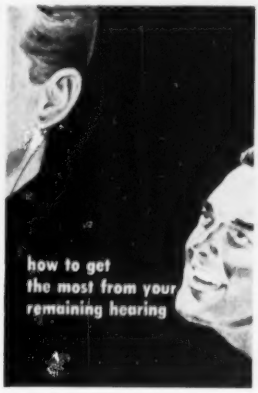

This new book is an excellent aid in helping the hard-of-hearing to minimize their difficulty. It contains 46 pictures, charts and diagrams, as well as several exercises for improvement of hearing.

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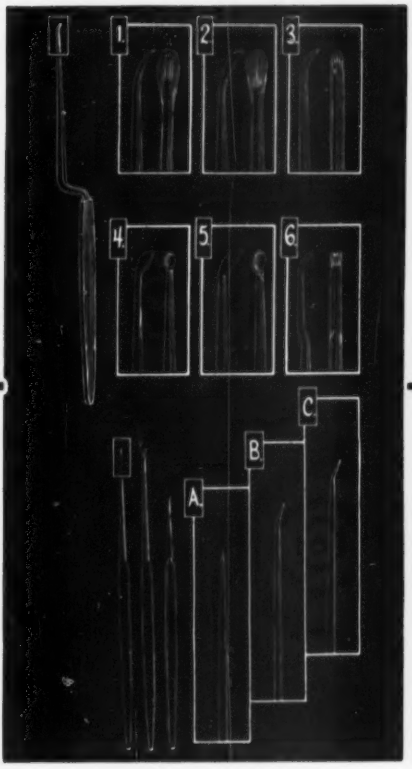

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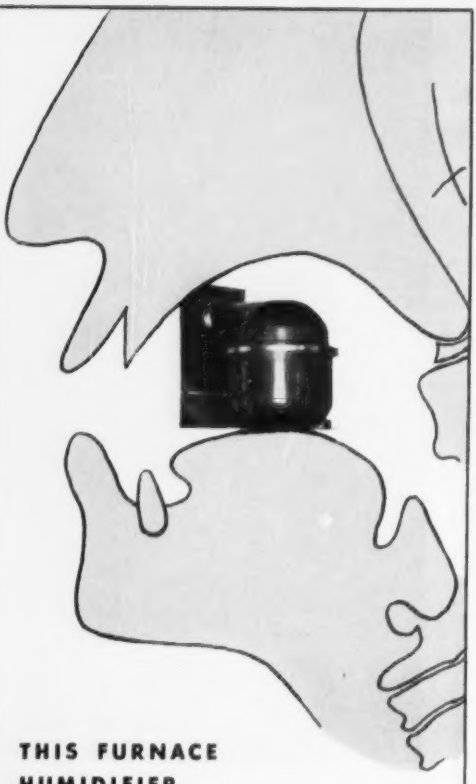

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Ref. Archives of Otolaryngology, February 1953

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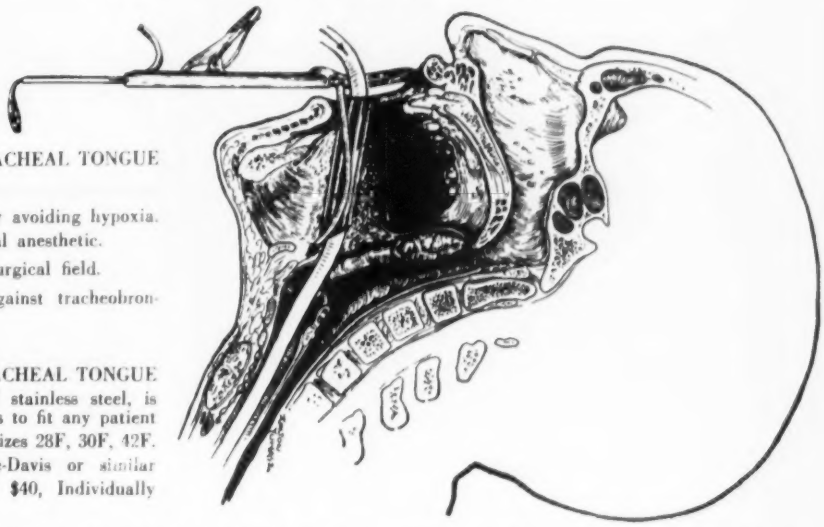

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*Barton, R. T.: Instrument for endotracheal anesthesia during oro-pharyngeal surgery. J. A. M. A. 153:1017 (Nov. 14) 1953.

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